LANDSAT TO GROUND STATION INTERFACE DESCRIPTION

REVISION 9

JANUARY 1986

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

REVISION PAGE

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*Note that the black bars in the page margins are effective only for current revisions and change notices.

PREFACE

Revision 9 of the Landsat to Ground Station Interface Description updates Revision 8 of the document published in June 1984.

Major updates were made in Revision 8 in order to include the Landsat-5 mission:

- Modification of the title to delete reference to the Landsat-4 mission in favor of using the generic Landsat title

- Elimination of references in the text to the Landsat-4 mission and substitution of the term "Landsat" where the reference was applicable to both the Landsat-4 and Landsat-5 missions

- Addition of mission-specific information for Landsat-5 where such information is included for Landsat-4.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

ILLUSTRATIONS

ILLUSTRATIONS (continued)

ILLUSTRATIONS (continued)

TABLES

TABLES (continued)

TABLES (continued)

TABLES (continued)

TABLES (continued)

ACRONYMS AND ABBREVIATIONS

ACS	Attitude control system
A/D	Analog to Digital
ADS	Angular displacement sensor
ADSA	Angular displacement sensor assembly
BCD	Binary-coded decimal
BER	Bit error rate
Biφ-M	Biphase mark
BPSK	Balanced phase-shift key
Cal	Calibration or calibrate
CCT	Computer-compatible tape
CMD	Command
CU	Control Unit
C	Centigrade
dB	Decibel
dBW	Power in decibels, referenced to 1 watt
DEMUX	Demultiplexer
Domsat	Domestic Communications Satellite
DPU	Data processing unit
DRIRU	Dry rotor inertial reference unit
ECI	Earth centered inertial
EOL	End of line
EP	Euler parameter
EROS	Earth Resources Observation System
FPA	Focal plane assembly
FS	Flight segment
GMT	Greenwich mean time
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
HAC	Hughes Aircraft Company
HDT	High-density tape
IC	Internal calibration
ID	Identification
IFOV	Instantaneous field of view
IIRV	Improved Interrange Vector
IRU	Inertial reference unit
kbps	Kilobits per second
L/F	Low frequency
LGSID	Landsat to Ground Station Interface Description
LGSOWG	Landsat Ground Station Operations Working Group
LSB	Least significant bit

ACRONYMS AND ABBREVIATIONS (continued)

Mbps	Megabits per second
MFID	Minor-frame Identification
MHz	Megahertz
MMS	Multimission Modular Spacecraft
MNFS	Minor-frame synchronization
MSB	Most significant bit
msec	Millisecond
MSS	Multispectral Scanner
MUX	Multiplexer
NASA	National Aeronautics and Space Administration
NETD	Noise equivalent temperature difference
NRZ	Nonreturn to zero
NRZ-L	Nonreturn to zero level
NRZ-M	Nonreturn to zero mark
OBC	Onboard computer
OCC	Operations Control Center
PCD	Payload correction data
PCM	Pulse-code modulation
PDU	Power distribution unit
PF	Protoflight
PM	Phase modulated
PN	Pseudonoise
$\overline{PN}$	Not PN
PSK	Phase-shift keyed
rad	Radian
RIU	Remote interface unit
rms	Root mean square
SAM	Scan angle monitor
SLC	Scan line corrector
SLS	Scan line start
SMA	Scan mirror assembly
SME	Scan mirror electronics
S/N	Signal to noise
S/NR	Signal-to-noise ratio
TBD	To be determined
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TGS	Transportable Ground Station
TLM	Telemetry
TM	Thematic mapper
TWT	Traveling wave tube
TWX	Teletype message
UQPSK	Unbalanced quadrature phase-shift keyed
UTC	Universal Time, Coordinated

LANDSAT TO GROUND STATION
INTERFACE DESCRIPTION

1. LANDSAT MISSION OVERVIEW

1.1 FLIGHT SEGMENT

Figure 1 is an illustration of the components of the Landsat flight segment.

1.2 ORBIT

The Landsat orbit is defined as follows:

Altitude	705.3 km
Inclination	98.2 degrees
Repeat cycle	16 days
Orbits per cycle	233
Ground trace spacing at Equator	172.0 km
Sidelap at Equator	7.6 percent
Descending node time	0930 to 1000 hours
Nodal period	5933.0472 seconds

The value of 705.3 for the Landsat orbit agrees with the altitude over the Earth's Equator (h_e) that satisfies a Keplerian period (P) corresponding to the design nodal period. The 705.3-km altitude is not intended for use in detailed orbital analyses because it does not precisely represent the actual Landsat altitude at the Equator.

a is altitude measured from the center of the Earth.

$$P = 2\pi\sqrt{\frac{a^3}{\mu}} \quad P = 5933.0472 \text{ sec}; \ \mu = 398601.2 \ \frac{\text{km}^3}{\text{sec}^2}.$$

$$a = 7083.465 \text{ km} \ r_e = 6378.165 \text{ km}.$$

$$h_e = a - r_e = 705.3 \text{ km}.$$

Figure 2 shows the Landsat orbit for the 16-day period. Landsat-5 coverage will normally be separated from Landsat-4 coverage by 8 days. Maps and information regarding nominal ground track and scene-center locations for both Landsat-4 and Landsat-5 will be available from the Earth Resources Observation System (EROS) Data Center, Sioux Falls, South Dakota.

1.3 FUNCTION OF LANDSAT ATTITUDE CONTROL SYSTEM

The Landsat spacecraft attitude control system (ACS) orients the spacecraft relative to a desired target. The central control system element is an onboard computer (OBC) that processes all sensor-derived information and, in conjunction with various types of

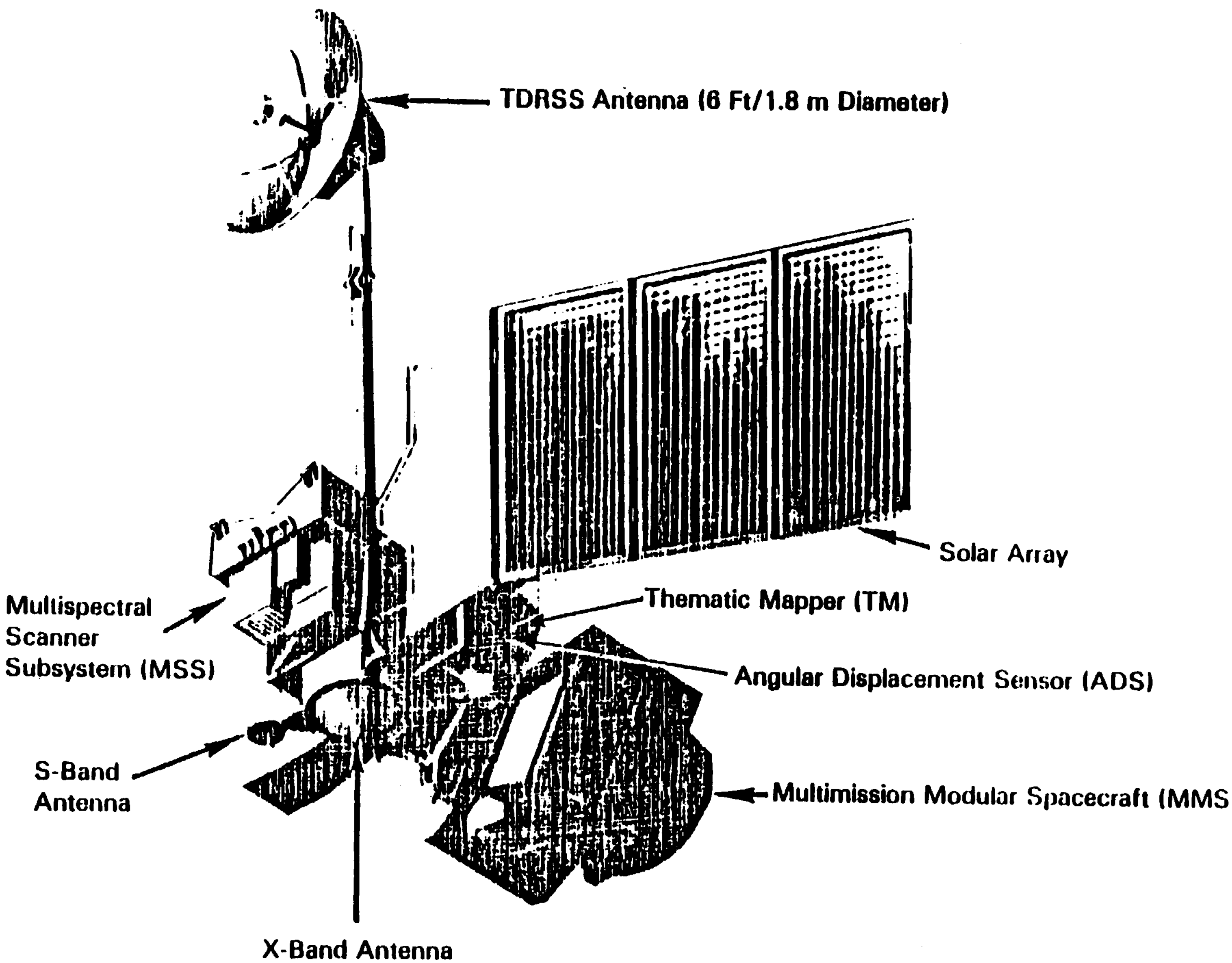


Figure 1. Landsat Flight Segment

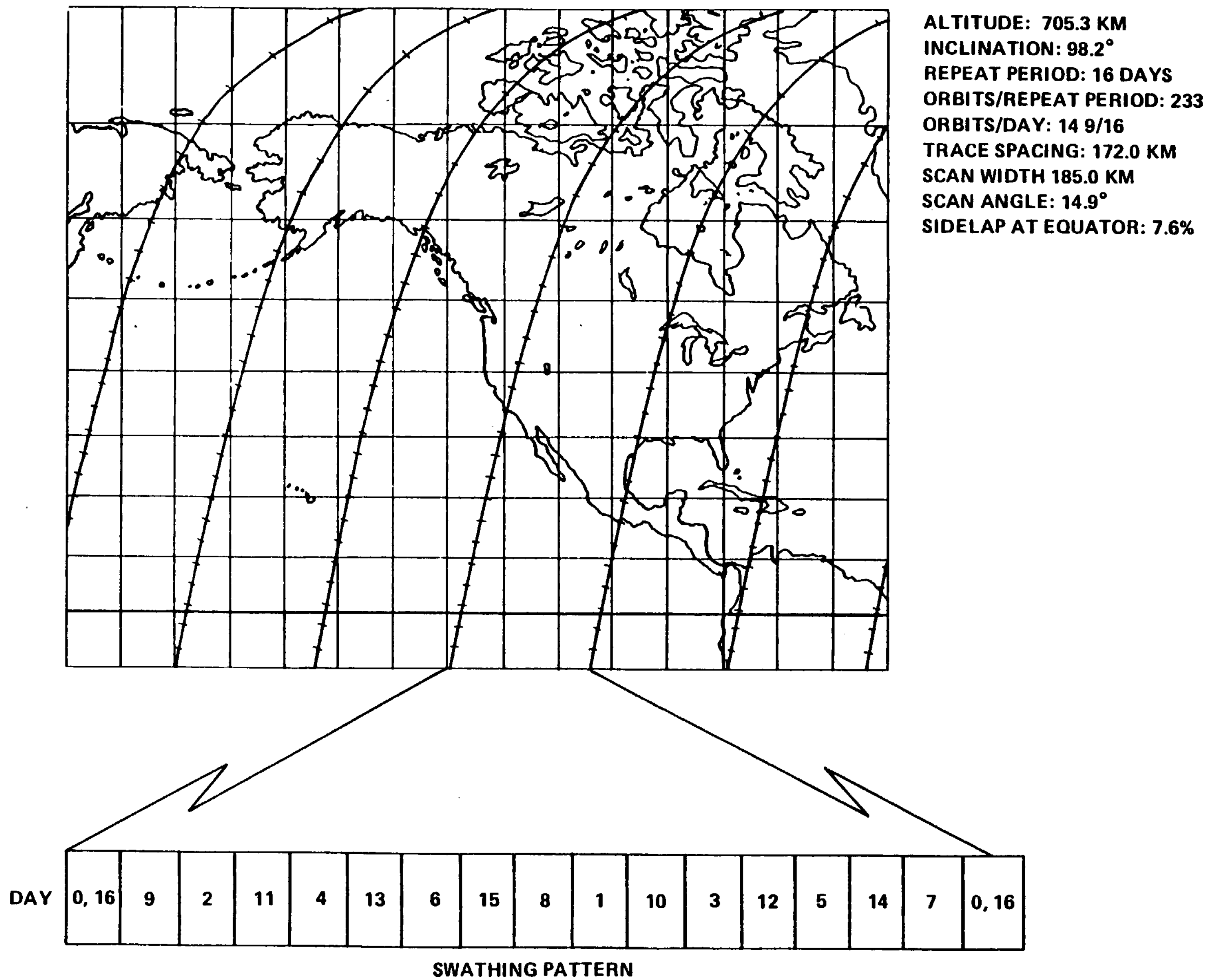


Figure 2. Swathing Pattern for One Satellite (16-Day Coverage)

stored information, generates the appropriate control signals to operate the spacecraft reaction control devices. The Landsat reference sensor system consists of coarse Sun sensors, an Earth sensor (for safe-hold only), an inertial reference unit (IRU), a pair of fixed-head star trackers, and a three-axis magnetometer. All sensor outputs are transferred to the OBC in addition to being downlinked in telemetry. The OBC processes the sensory inputs and derives the control equipment commands. The primary attitude reference is derived from the IRU. The IRU bias drift and scale factor errors are computed within the OBC through use of known target stars. A 1-sigma pointing accuracy of 0.01 degree is expected from this system.

1.4 COMMUNICATIONS

Figure 3 shows the overall data flow from Landsat. Foreign ground stations will receive data by X- and S-band links. For more information concerning these data transmissions, refer to Section 9.

1.5 NASA/GODDARD SPACE FLIGHT CENTER (GSFC) LANDSAT USER PRODUCT SPECIFICATIONS

a. NASA/GSFC intends to maintain the Landsat-4/-5 Data Management System MSS partially processed output high-density tape (HDT-A) format compatible with the Landsat-3 format family currently in use within the GSFC/Image Processing Facility.

b. MSS user photographic and computer-compatible tape (CCT) products will not be produced by GSFC. The EROS Data Center will be responsible for producing these user products.

c. The TM high-density tape (HDT), CCT, and photographic output product formats have been defined in Interface Control Documents 2501 and 2801. However, plans are being made to conform the formats as closely as possible to the generic structure of the HDT and photographic products currently being used for Landsats-2 and -3. GSFC intends to use the Martin Marietta Model MH2879-L high-data-rate recorders and the Goodyear Landsat-4 high-resolution film recording system.

Additional product information should be obtained from the EROS Data Center, Sioux Falls, South Dakota.

2. ATTITUDE AND EPHEMERIS DATA

NASA/GSFC plans to provide attitude and ephemeris data for use in processing image data to Landsat Ground Station Operations Working Group (LGSOWG) members on a routine basis within the telemetry 8 kbps S-band downlink and TM video data.

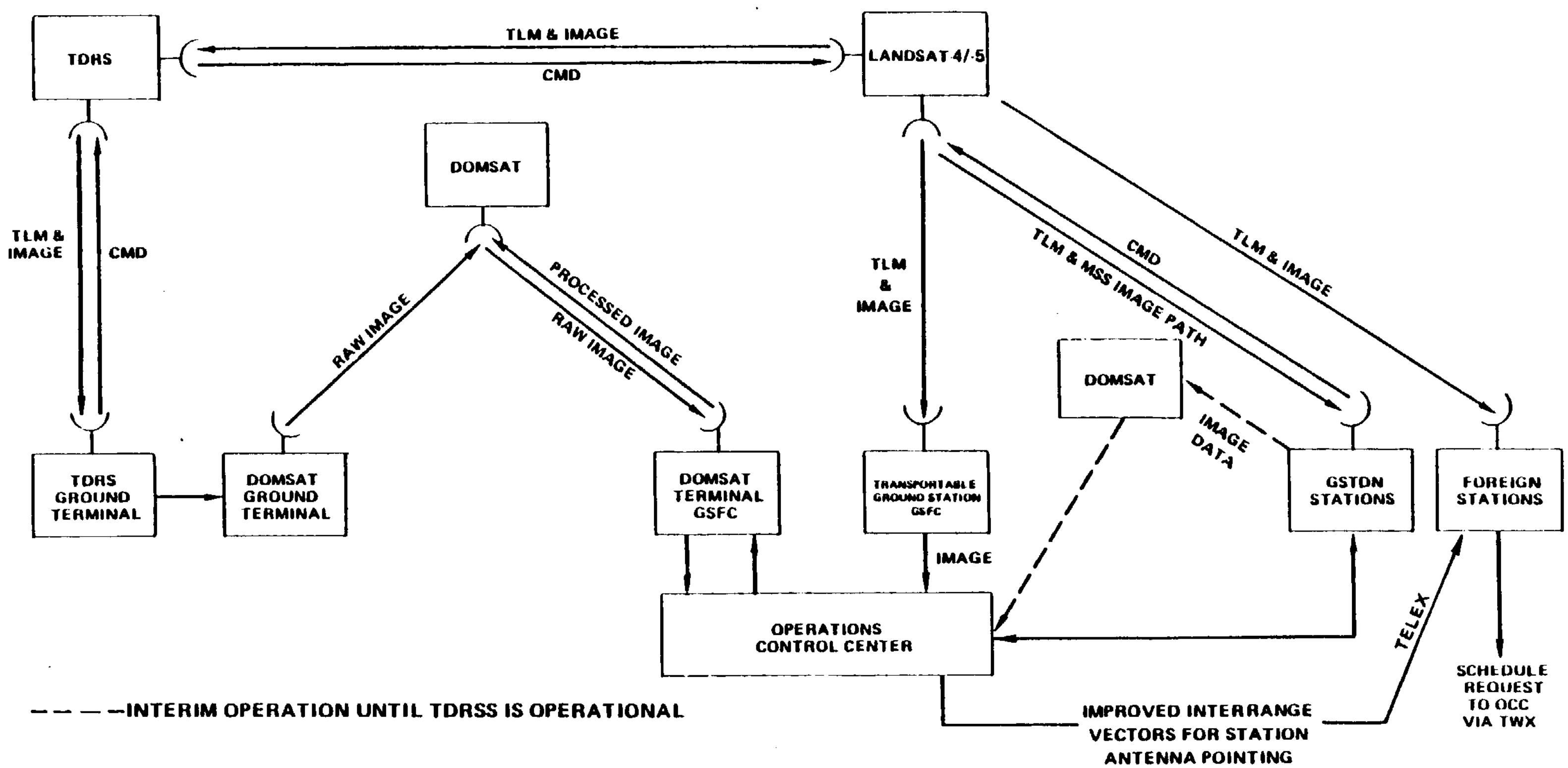


Figure 3. Landsat Overall Data Flow

The ephemeris data, which are provided in the form of orbital-state vectors, will be derived by the spacecraft OBC from uplinked predicted ephemeris data. The accuracy of these data is presented in Table 1 and the content and data format are described in Section 5. The ephemeris data provided within the telemetry S-band downlink and TM video data will normally be between 1 and 2 days after tracking data cutoff. Onboard ephemeris processing by the OBC does not introduce any significant degradation to the accuracies defined in Table 1.

Table 1
Ephemeris Location Accuracy
(1 sigma)

Source	Position/Location Accuracy (meters) (days from tracking cutoff)		
	1	2	3
Predicted-fit ephemeris	250	500	1000

Landsat pointing accuracy will be 0.01 degree (1 sigma). Pointing, ephemeris, alignment of the TM to the pointing axis, and timing errors will result in positional accuracy of the imagery with systematic correction only (no use of ground control points) as summarized below:

Error Source	Cross Track (Meters 1σ)	Along Track (Meters 1σ)
Ephemeris	100	500
Time	N/A	80
Attitude	123	123
Alignment	427	855
Total (root-sum-square)	455	1001

The altitude of the Landsat orbit, considering both orbit eccentricity and the Earth's figure, will vary between about 696 and 741 kilometers. Maximum altitudes will occur over the North and South Poles and minimum altitudes will occur over equatorial regions.

The Landsat ACS-pointed axis is defined as the line of sight from the spacecraft of the geocenter (i.e., the origin of the Earth-centered inertial true-of-date coordinate system). This is also the nominal alignment axis for the optical axes of both the TM and the MSS. Detailed alignment data are provided in Appendix F.

3. NAVIGATIONAL DATA

NASA plans to provide improved interrange vectors (I^2RV) by Telex, which allow proper pointing of ground station antenna for acquisition of satellite data signals. These vectors will be provided daily, at least 24 hours before becoming effective. The I^2RV message is described in Appendix D. Orbital element and state vector data are available from NASA as an alternative to I^2RV messages until the capability to accept I^2RV data is implemented by LGSOWG members. Orbital element data are estimated to be in the range of 2 km accuracy.

4. MULTISPECTRAL SCANNER SPECIFICATIONS

4.1 MULTISPECTRAL SCANNER RADIOMETRIC SPECIFICATIONS

4.1.1 Spectral Bands

The MSS operates in four spectral bands in the solar-reflected spectral region as follows:

a. Band 1--0.5 to 0.6 micrometers
b. Band 2--0.6 to 0.7 micrometers
c. Band 3--0.7 to 0.8 micrometers
d. Band 4--0.8 to 1.1 micrometers

4.1.2 MSS Detectors

The MSS uses the following detectors in each spectral band:

a. Band 1--Photomultiplier tube (six each)
b. Band 2--Photomultiplier tube (six each)
c. Band 3--Photomultiplier tube (six each)
d. Band 4--Silicon photodiode (six each)

4.1.3 MSS Radiance/Signal Range

The scanner provides video signals that are accurately related to radiance values in each spectral band. The maximum radiance levels for Bands 1 through 4 are:

Band	Maximum Radiance 10^{-4} watts cm^{-2} $ster^{-1}$
1	24.8
2	20.0
3	17.6
4	46.0

NASA has no plans to acquire Sun calibration data for the MSS.

4.1.4 MSS Quantization

Each sample is encoded into a 6-bit word using rounding quantization.

4.1.5 MSS Signal-to-Noise Ratio (SNR)

The ratio of output signal level to root mean square (rms) noise input radiance for the scanner and the multiplexer is required by instrument specification to be as defined in Table 2 when the multiplexer samples are in the linear mode. When the multiplexer compresses signals from Bands 1, 2, and 3, the SNR's are similarly required to be as defined in Table 3. The specified SNR's prior to quantization are defined in Table 3a.

4.2 MSS SCANNING MIRROR CHARACTERISTICS

4.2.1 MSS Geometric Accuracy

The Landsat MSS scan mirror is supported by two flex pivots that exert a restoring torque on the mirror. The torque is zero at approximately the center of scan. Bumpers are provided at the two ends of scan to reverse the mirror angular velocity. During the "active" scan (west to east in the spacecraft descending node) when video data are collected, the mirror is essentially torque-free except for the flex-pivot torque. During the reverse or back-scan, a torque motor applies torque to restore the system energy lost during the previous scan cycle. The mirror inertia is approximately 0.0077 slug-ft^2 and the combined spring constant of the flex pivots is approximately 4707 ft-lb per radian.

4.2.2 Scan Mirror Assembly

Sensor ground coverage perpendicular to the satellite track is accomplished by means of a flat scanning mirror oriented at 45 degrees with respect to the scene that scans about the X-axis. The following parameters define this scan mirror assembly system:

a. Scan frequency: 13.62 Hz $\pm$0.01 percent

b. Scan angle across scene: 14.90 $\pm$0.06 degree or 0.26 $\pm$0.001 radian

c. Timing format (Figure A-2)

d. Active scan period: 32.75 $\pm$1.25 milliseconds

4.2.3 Geometric Fidelity

Geometric fidelity shall be defined by:

a. Lines per scan (scanned simultaneously)--Band 1 through Band 4: 6

b. Scan-to-scan line-length variation--42.0 μr, rms over 100 scans (the variation will be larger when operated simultaneously with the TM instrument)

Table 2
Specified SNR After Quantization
(Linear Mode)

	Band			
	1	2	3	4
High-radiance level:				
Minimum system signal-to-noise (S/N) output (after analog to digital (A/D) conversion)	89	73	50	104
1/2 high-radiance level:				
Minimum system S/N output (after A/D conversion)	54	46	33	54

Table 3
Specified SNR After Quantization
(Compression Mode)

	Band		
	1	2	3
High-radiance level:			
Minimum system S/N output (after A/D conversion)	75	65	47
1/2 high-radiance level:			
Minimum system S/N output (after A/D conversion)	43	38	30

Table 3a
Specified SNR Prior to Quantization

Specified Requirement	Band 1	Band 2	Band 3	Band 4
High-radiance (MW/CM^2-Sr)	2.48	2.0	1.76	4.6
Minimum SNR at high-radiance	124	94	59	189
1/2 high-radiance (MW/CM^2-Sr)	1.24	1.0	0.88	2.3
Minimum SNR at 1/2 high-radiance	87	66	41	94

c. Optical centerline variations--Less than 1 percent of full scan

d. Scan repeatability--Scan angle versus time is repeatable within 24 μr, rms over 100 scans after line-length correction

e. Scan nonlinearity--For the linear portion of the forward scan, the repeatable scan rate deviates by less than +2.4, -5.0 percent from the mean scan rate.

4.3 MSS INTERNAL CALIBRATION

There are provisions in the MSS for internal calibration.

4.3.1 Bands 1 through 4 Internal Calibration

The internal calibration is provided on every other mirror scan cycle (major frame). Data on the alternate cycles are black level (dc restore in Band 4). A redundant source and varying neutral density filter will generate appropriate radiant levels and spectral distribution to provide internal calibration for Bands 1 through 4. The internal calibration for Bands 1 through 4 consists of a decreasing gray optical wedge (ramp calibrate) input of 10.2 ±2 milliseconds duration that occurs 42.8 ±2 milliseconds after line-start code (nominally 11 milliseconds after end-of-line code). Preflight gray-wedge test data will be supplied to the Landsat-4/-5 ground stations for all modes of operation. A typical gray-wedge calibration curve is shown in Figure 4. The middle two bits of the binary words are inverted as is the case for all video data.

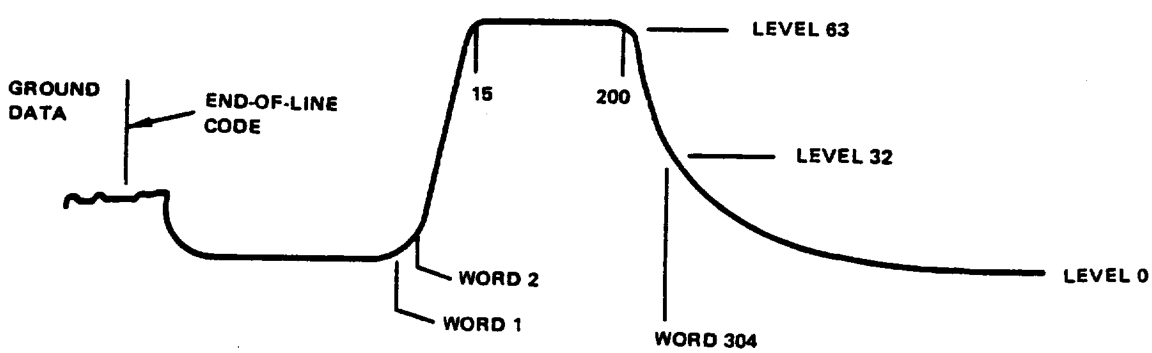


Figure 4. Typical Gray-Wedge Calibration Curve

4.3.2 MSS Internal Calibration Accuracy

For the maximum duty cycle period beginning 3 minutes after turnon (normal warmup time), the calibration wedge output is required by instrument specification to provide the means to calibrate gain and offset values for Bands 1 through 4 (paragraph 4.1.1) within the following relative accuracies.

a. Channel to channel (within a band)

   (1) Ratio of gains between channels: 2.0 percent peak to peak

   (2) Offset differences between channels: ±15 millivolts (less than 0.24 quantum average)

b. Band to band

   (1) Ratio of band average gain (average of six channels) between bands: ±30 millivolts (less than 0.47 quantum level average)

c. Stability at any channel

   (1) Gain change: ±2.0 percent over the maximum duty cycle

   (2) Offset change: ±12 millivolts over the maximum duty cycle period (less than 0.19 quantum level average)

The amplitude range of the calibration signal in the low-gain mode varies from a maximum of greater than 3.5 volts (level 55) to a minimum of less than 0.5 volt (level 8), and in the high-gain mode (Bands 1 and 2 only) from a maximum of greater than 4.0 volts (saturated level 63) to a minimum of less than 2.0 volts (level 32).

4.4 MSS SENSOR OUTPUT FORMAT

With the exception of the addition of a 4-bit spacecraft identification word, the MSS time-code format for Landsat-4/-5 is identical to the 4-band format of Landsats-1, -2, and -3. The MSS data format for Landsat-4/-5 is described in Appendix A.

4.5 MSS DATA PROCESSING CONSTANTS

The values of certain spacecraft and sensor constants required in ground processing are provided in Appendix B.

5. THEMATIC MAPPER SPECIFICATIONS

5.1 THEMATIC MAPPER RADIOMETRIC REQUIREMENTS

5.1.1 Radiometric Sensitivity

The TM output in each of Bands 1 through 5 and 7 have a SNR for specified input in accordance with Table 4. For a constant input radiance, the SNR is defined as the ratio of the output value (in units of radiance) averaged over at least 100 samples to the rms

Table 4
Thematic Mapper Signal-to-Noise Ratios

Band	Constant in Band Input Radiance (mw/cm^2-sr)	Minimum SNR
1	0.28	32
2	0.24	35
3	0.13	26
4	0.19	32
5	0.08	13
7	0.046	5

value of the noise equivalent radiance that is defined as the rms of the deviations of the output samples from the average value.

The sensitivity of Band 6 is specified in terms of noise equivalent temperature difference (NETD). The NETD for Band 6 as measured after at least a 6-pixel settling time at 300 K is 0.5 K. The minimum scene temperature for this band is 260 K.

The peak-to-peak signal variation across a scan line when scanning a uniform radiance scene is specified not to exceed 0.5 percent of the average output signal of the channel during the scan. For Band 6, this peak-to-peak signal variation is specified not to exceed 0.5 percent of the full scale signal.

5.1.2 Radiometric Accuracy

Relative radiometric accuracy between bands operating in the reflective region shall be better than 2 percent. To maintain radiometric measurement accuracy for the total mission duration, an internal reference source is used to provide calibration data for ground correction. In addition, a dc restore technique is used on board to minimize the effects of low frequency noise and drift. A zero-radiance level is applied to the sensors when the shutters are closed to develop a zero-clamp level for the A/D circuitry. This zero-clamp level is fractionally updated before each sweep. The zero-clamp level appears as a sensor black-level output to the ground during the shutter-closed period. NASA has no plans to acquire Sun calibration data for the TM.

5.1.3 Spectral Bands

The scanner is specified to operate in seven spectral bands in the solar-reflected spectral region as follows:

a. Band 1--0.45 to 0.52 micrometers
b. Band 2--0.52 to 0.60 micrometers
c. Band 3--0.63 to 0.69 micrometers
d. Band 4--0.76 to 0.90 micrometers

e. Band 5--1.55 to 1.75 micrometers
f. Band 6--10.40 to 12.50 micrometers
g. Band 7--2.08 to 2.35 micrometers

5.2 THEMATIC MAPPER GEOMETRIC CHARACTERISTICS

5.2.1 TM Geometry

The relationship between the Earth's surface and the data sampled by each TM detector is described in this section. The TM scan mirror is a 16- by 21-inch ellipse that provides a nearly linear scan motion covering a swath on the ground 185-km wide. A precision digital controller drives the mirror. A scan-line corrector, located behind the primary optics, compensates for the forward motion of the spacecraft and allows the scan mirror to produce usable data in both scan directions. Figure 5 shows the critical TM scanning components and the geometric relationship of the TM detectors to their ground-track projection.

Figures 6 and 7 give details of the detector geometry. The detector rows within a band are separated by 2.5 instantaneous fields of view (IFOV's). This is done because the multiplexer samples the even detectors 0.5 IFOV later than the odd detectors within a minor frame of data. In this way, the odd and even detectors are an integral multiple of IFOV's apart in space. The spacing between Bands 5 and 6 is 34.75 IFOV's so that the edge of Band 5 detectors will line up with the edge of a Band 6 detector. Note that the Band 5 detector edge is 0.75 IFOV from the center line of the band, while the edge of the Band 6 detector is 3.0 IFOV's from the center line. As shown in Figure 7, there are 37 IFOV's between the trailing edge of Band 6 Detector 1 and Band 5 odd detectors in the forward direction, and 40 IFOV's in the reverse direction. Table 5 gives the minor frame adjustments between detectors. It includes nominal physical spacing and sample timing.

5.2.1.1 Sample Timing--As shown in Figure 7a, the values of Band 6 Detectors 1 and 3 are held immediately after the line start code. The Band 6 Detector 1 sample is placed into the first minor frame after line start, and the sample of Band 6 Detector 3 is placed into the second minor frame. At the beginning of the third minor frame, the values of Band 6 Detectors 2 and 4 are held. The Band 6 Detector 2 sample is placed into the third minor frame, and the sample of Band 6 Detector 4 is placed into the fourth minor frame. The above process is then repeated starting with the fifth minor frame.

The odd detector values of Bands 1 through 5 and 7 are held at the beginning of each minor frame. The even detector values of Bands 1 through 5 and 7 are held at the mid-point of each minor frame. All detector values for Bands 1 through 5 and 7 are placed into the minor frame at which they are held. When the detector layout

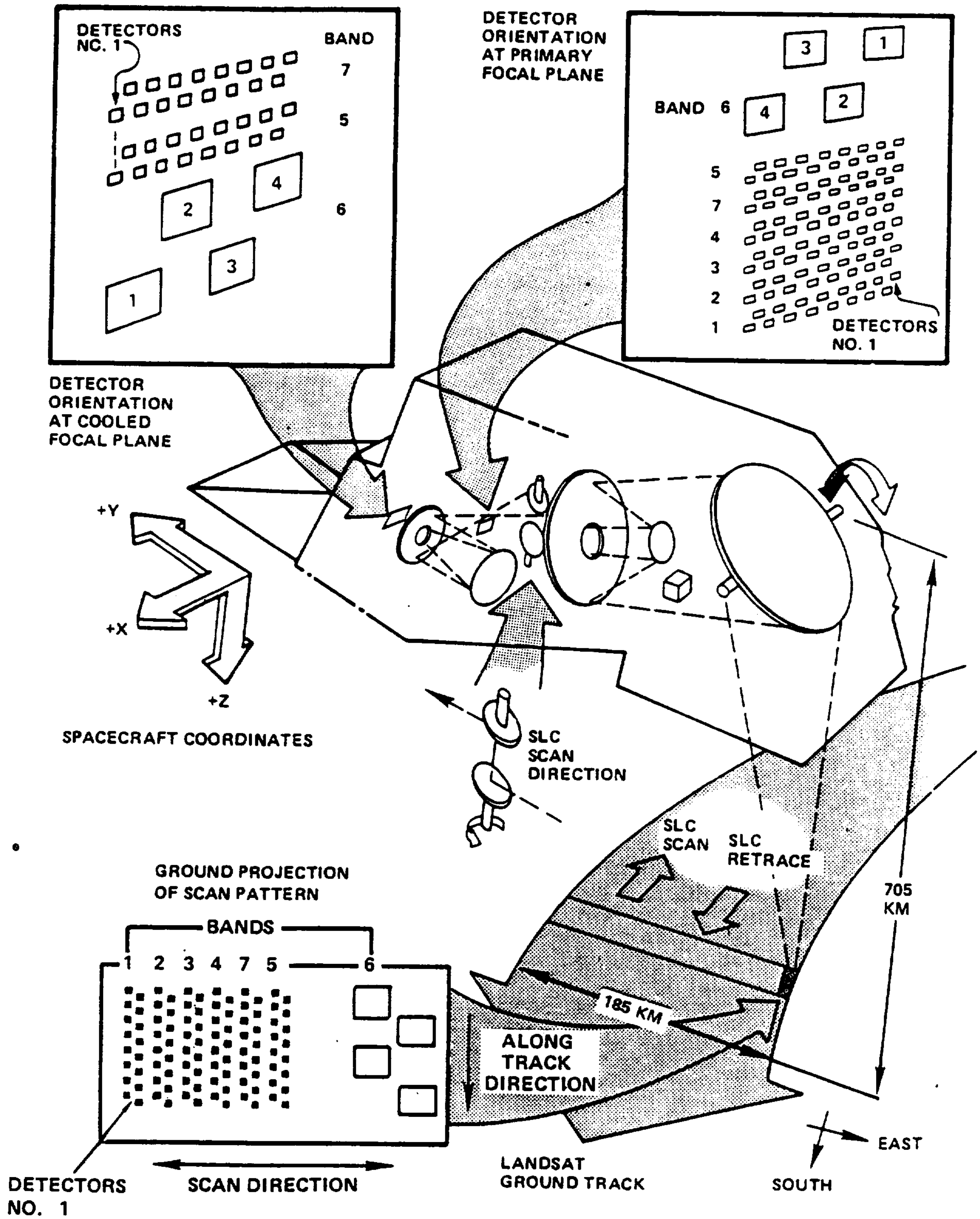


Figure 5. Detector Array Projections on Ground Track

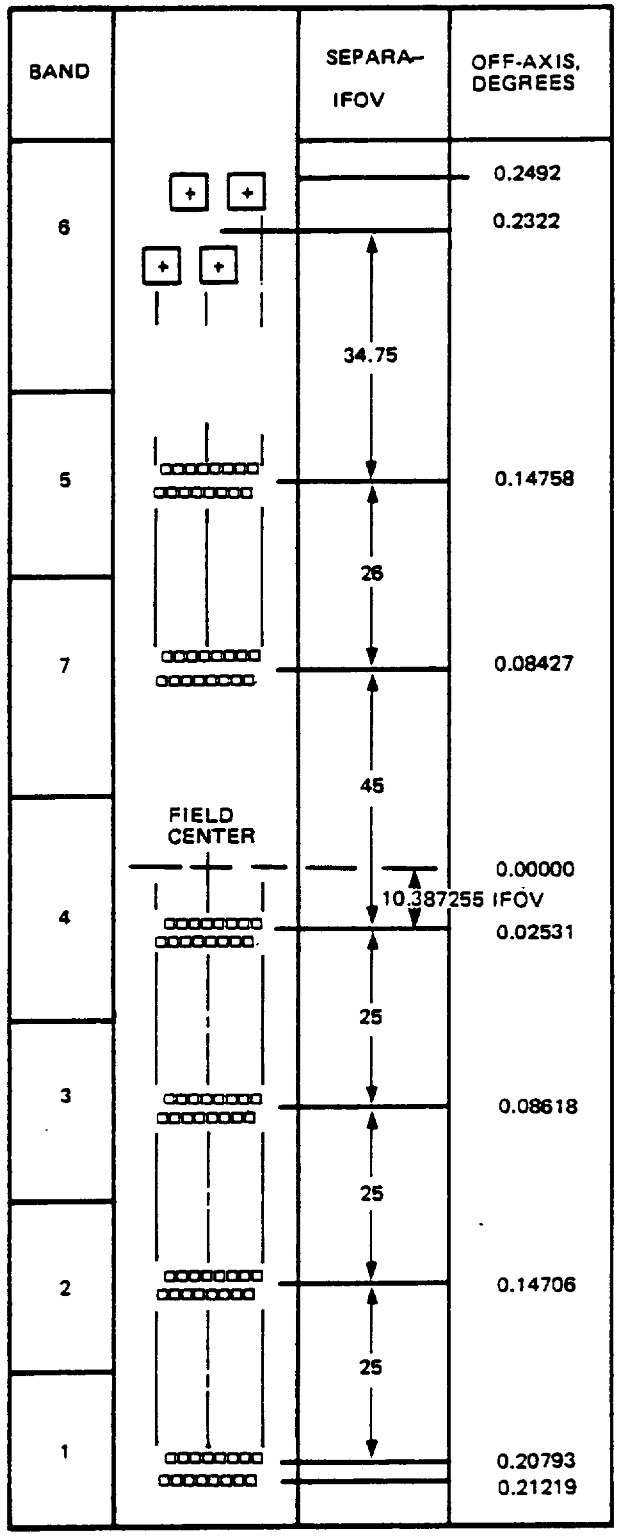


Figure 6. Detector Projection at Prime Focal Plane

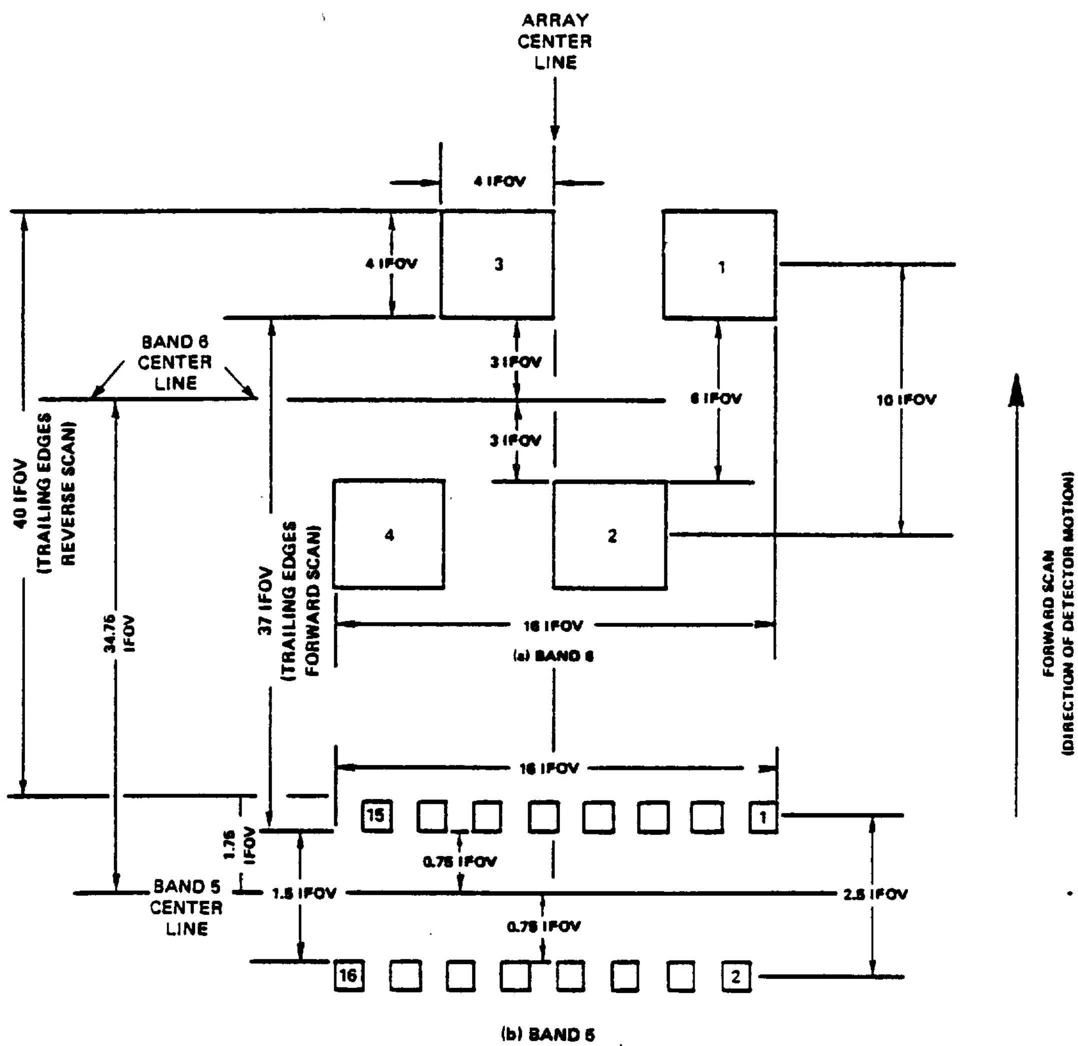


Figure 7. Details of Detector Spacing

Table 5
Detector Adjustments for Layout Geometry and Multiplexer Sampling

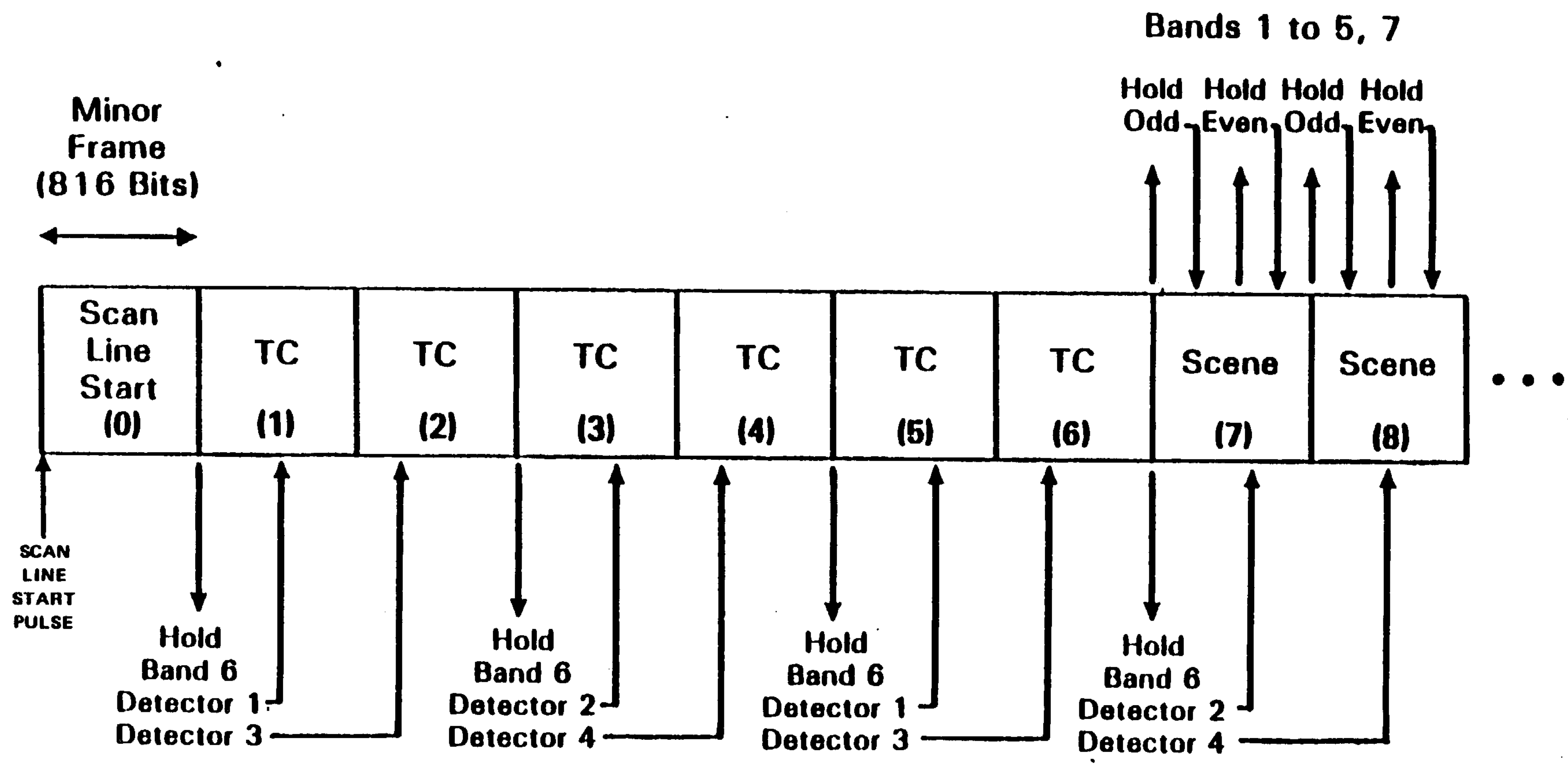
Scan Direction	Minor-Frame Adjustment	
	Reverse Scan (east to west)	Forward Scan (west to east)
Band 1 even	+3	-2
Band 1 odd	0	0
Band 2 even	-22	23
Band 2 odd	-25	25
Band 3 even	-47	48
Band 3 odd	-50	50
Band 4 even	-72	73
Band 4 odd	-75	75
Band 7 even	-117	118
Band 7 odd	-120	120
Band 5 even	-143	144
Band 5 odd	-146	146
Band 6 1	-186	183
Band 6 2	-174	175
Band 6 3	-187	182
Band 6 4	-175	174

Note: One Band 6 detector is sampled per minor frame. The sequence from line start is detector 1,3,2,4,1,3,2,4,1...

and sample timing effects shown in Figures 6, 7, and 7a are combined, the minor frame adjustments defined in Table 5 result. For example, there are nominally 37 minor frame samples between the trailing edges of Band 6 Detector 1 and odd Band 5 detectors on forward scans. Band 6 Detector 3 samples are placed in the minor frame after the Band 6 Detector 1 sample. Thus, there are 36 minor frame samples between odd detectors of Band 5 and Band 6 Detector 3 on forward scans.

For reverse scans, the values of Table 5 again represent the minor frame adjustment between the trailing edges of Band 6 detectors and the other bands.

5.2.1.2 TM Scanning Mirrors--The scan mirror assembly (SMA) operates in two modes: scan angle monitor (SAM) mode and bumper mode. The bumper mode is a third backup and will not be addressed in this document. The SAM mode can operate with scan mirror electronics number 1 (SME-1) or scan mirror electronics number 2 (SME-2). For each SME, there exists a fifth-order polynomial describing the nominal departure from linearity (or profile) of the scan mirror forward and reverse scans. (See Appendix C.) These nominal polynomial profiles must be adjusted on the basis



( ) = Minor Frame Number
TC = Time Code (Spacecraft Time at Scan Line Start)

Figure 7a. TM Sample Timing

of first half and second half scan time data due to observed profile wander (expected to be a slowly varying adjustment of ±10 microradians at midscan over 2000 scans) and due to launch vibration profile shifts (expected to be less than ±200 microradians at midscan).

Appendix E, TM Midscan Correction Summary, explains how a parabola is added to a smoothed profile polynomial to create a ground calibrated profile polynomial.

The scan mirror electronics (SME) mode is indicated in Bits 6 and 7 of TM serial Word E. Serial Word E is given within the PCD TM housekeeping telemetry. See Section 5.4.7.2 (k).

The scan mirror produces nonlinear motions normal to its scan direction. This produces cross-scan or along-track errors that are defined using the polynomials given in Appendix C.

The scan line corrector (SLC) scans in the along-track direction and is intended to remove the along-track spacecraft and along-track Earth-rotation motion during the active scan time. The SLC position is reset by the end-scan pulse and initiates along-track scanning before the start-scan time. The SLC position at start-scan is a function of scan mirror turnaround time. The following are nominal SLC parameters:

Scan frequency (nominal)	13.99 Hz
Scan period (nominal)	71.462 ms
Scan rate in object space (nominal)	9.6 mr/sec

5.2.2 TM Geometric Accuracy

A line synchronization signal is generated once each scan line. The signals relate the position of the scanning system with respect to the TM frame.

Excluding the effects of possible spacecraft attitude changes, the path of any detector on the ground will not deviate from a straight line by more than 1.0 IFOV (maximum) during the active portion of each scan. The scan profile (angular position versus time) can be described to within 0.1 IFOV (rms) by a smooth function of time with a maximum of three inflection points. A calibration profile has been derived from data taken during scan mirror subsystem tests and is provided in Appendix C.

The scan profiles in both along-track and cross-track directions are specified to be repeatable to the calibration profiles to within 0.1 IFOV (rms) over 400 scans and to within 0.2 IFOV (rms) over the operational lifetime of the instrument. To meet the scan profile repeatability requirements, scan profiles should be adjusted using first half scan time error and second half scan time error information that is provided in the high-data-rate stream.

The Flight Segment (FS) includes mechanical devices that are active during the time that images are being acquired. These mechanical devices cause low-amplitude motion that is passed through the spacecraft structure and results in attitude deviations of the TM optical axis. This motion is called jitter.

Observed rms TM jitter error, referenced to the spacecraft coordinate system, is as follows:

Frequency Range (Hz)	Error Magnitude (arc-sec, 1 sigma)
0--0.01	36 All axes
0.01--0.4	10 All axes
0.4--7	5 All axes
Greater than 7	2 Roll 1 Pitch 2 Yaw

Significant error does not occur above 77 Hz.

Because of the developmental nature of the TM system, the NASA ground processing system is being designed to accommodate larger worst-case (peak) jitter errors of 20 arc-seconds above 7 Hz. The amplitude and phase of jitter is expected to be asynchronous with respect to the TM scanning and thus requires measurement and correction during ground processing. The TM attitude measurement capability is up to nominally 2.0 Hz, using the attitude control inertial reference units (IRU's), and from nominally 2.0 to 125 Hz, using the angular displacement sensor (ADS). IRU and ADS outputs are combined on the ground to compute FS attitude deviations from nominal pointing. Below 125 Hz the TM is structurally rigid, and below 20 Hz the spacecraft center body is structurally rigid. ADS and IRU measurements fully characterize the attitude jitter of the TM optical axis.

5.2.3 TM Scan Rate

The scan rate (scene angular scan rate) during the usable portion of the scan is specified to deviate not more than 1 percent (peak) from the average scan rate over any 30-second time period.

5.2.4 TM Overlap/Underlap

The peak overlap or underlap of IFOV's in adjacent scan lines of a band, not including the effect due to variations in range across the scan (i.e., bow-tie effect), altitude variation, or spacecraft jitter will be less than 0.2 IFOV error (in 395 of 400 measurements) over the full length of the scan lines when viewing the Earth. This is an instrument-level specification value, which includes differential (forward/reverse) cross-scan scan mirror nonlinearity, SLC nonlinearity, and internal instrument vibration.

5.2.5 TM Scan-Line Length

The length of a scan line is defined as the time required for scanning between the images of two sources that are at opposite ends of the scanned field of view. The TM line length (active) will vary by no more than ±1 minor frame time from the line length averaged over 400 scans, exclusive of jitter effects external to the TM. Note that the specified performance (±1 minor frame) is for the active scan line length. In operation, the TM line length variation may be as large as ±20 minor frames when the TM and MSS operate simultaneously.

Major frame length (scan line start to the next scan line start) can vary up to an additional ±10 minor frames due to variation in mirror turnaround times.

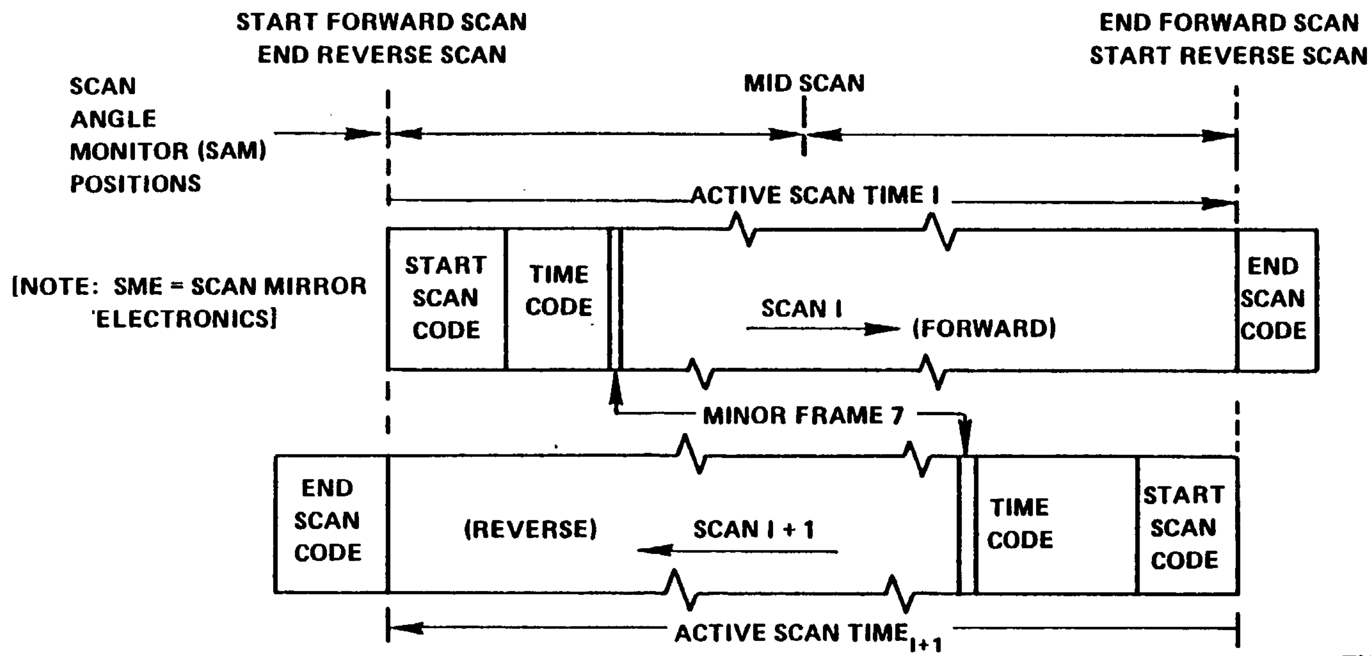
5.2.6 Forward to Reverse Scan Alignment

Because alternate image line sets are scanned in opposite directions, the data must be manipulated to construct a sensible image. In addition to reversing the order in which detector values are positioned on alternate sets, the data must be aligned to preserve proper along-track registration. A simplified illustration of the alignment required is shown in Figure 7b. Also shown are the approximate magnitudes of errors which would result from not including various factors in the alignment process.

5.3 TM INTERNAL RADIOMETRIC CALIBRATION SYSTEM

An internal calibration system is provided within the TM instrument to assist in performing radiometric calibration of the image data. This system consists of an obscuration shutter assembly which includes a set of three calibration source lamps with associated optical conductors for Bands 1 through 5 and 7, and a temperature controlled blackbody surface for the thermal band (Band 6). The obscuration shutter also provides a zero-radiance surface for use in setting the dc reference level for Bands 1 through 5 and 7 within the instrument electronics, and provides a second known-temperature surface for use in thermal band calibration.

At the completion of each imaging scan, the obscuration shutter rotates into a range of positions in which the normal optical path for each detector is blocked. As the shutter passes through these optical paths, the calibration lamps, blackbody surface, and zero-radiance surfaces pass through the detector FOV's. As a result, calibration radiance levels and a dc restore level are provided between active scans for Bands 1 through 5 and 7 detectors, and two known-temperature levels are provided between active scans for Band 6 detectors. These data are intended for use in establishing calibration functions which can be applied to image data collected during each scan.



FACTORS AFFECTING FORWARD TO REVERSE ALIGNMENT

- DIFFERENCE IN ACTIVE SCAN TIME
- DETECTOR DELAY (INCLUDES SAM DELAY)
- DIFFERENT SCAN PROFILE
- ATTITUDE ERROR (MEASURED BY ANGULAR DISPLACEMENT SENSOR)

TYPICAL PEAK MAGNITUDE IN PIXELS

LANDSAT-4	LANDSAT-5
6	3.5
2.5	2.5
1.4	0.5
0.5	0.5

Figure 7b. Forward to Reverse Scan Alignment

5.3.1 Calibration Lamp System

The internal calibration system for Bands 1 through 5 and 7 provides calibration data over a span of approximately 50 pixels (~0.5 milliseconds) within each scan. On forward scans, the calibration data begins approximately 6.8 milliseconds after the end-of-line pulse (EOL), and on reverse scans the calibration data begins approximately 1.9 milliseconds after EOL. Based on prelaunch test observations of the Landsat-4 instrument, the shape of the calibration data radiance profile within each scan is not a simple step-function, and must be interpreted carefully. An example of a calibration pulse observed through a Band 3 detector of the Landsat-4 instrument during prelaunch test is shown in Figure 7c. In order to establish the value which corresponds to each calibration data level, NASA plans to average over 65 pixels centered on the calibration pulse.

The internal calibration lamps for Bands 1 through 5 and 7 can be operated in either an automatic mode or in a backup mode. In the automatic mode, an internal sequencer automatically switches between various lamp combinations to provide an eight-step sequence of calibration levels. This sequence is as follows:

Step	Lamp Configuration	Nominal Calibration Level* (percent of full scale)
1	All lamps OFF	0
2	Lamp A ON	40
3	Lamps A and B ON	70
4	Lamp B ON	30
5	Lamps B and C ON	50
6	Lamps A, B, and C ON	90
7	Lamps A and C ON	60
8	Lamp C ON	20

*Calibration radiance values provided in Appendix C.

Progression through this sequence is synchronized with scans such that each calibration level is present in approximately 40 consecutive scans. Examples of the exact calibration level sequence seen through two detectors of the Landsat-4 instrument during prelaunch test are shown in Figures 7d and 7e. Roughly 0.5 second is required for changing calibration levels because of the time required for the lamps to warm up to full radiance, or to cool down in the case of the infrared bands. For this reason, NASA plans to ignore nine scans surrounding each calibration level change, beginning one scan before the transition occurs, and continuing through seven scans after the transition has occurred. NASA also plans to determine lamp configuration by interpreting calibration data magnitude. (There are calibration lamp current monitors within the spacecraft housekeeping telemetry, but these are <u>not</u> intended for use in determining calibration lamp configuration; these monitors

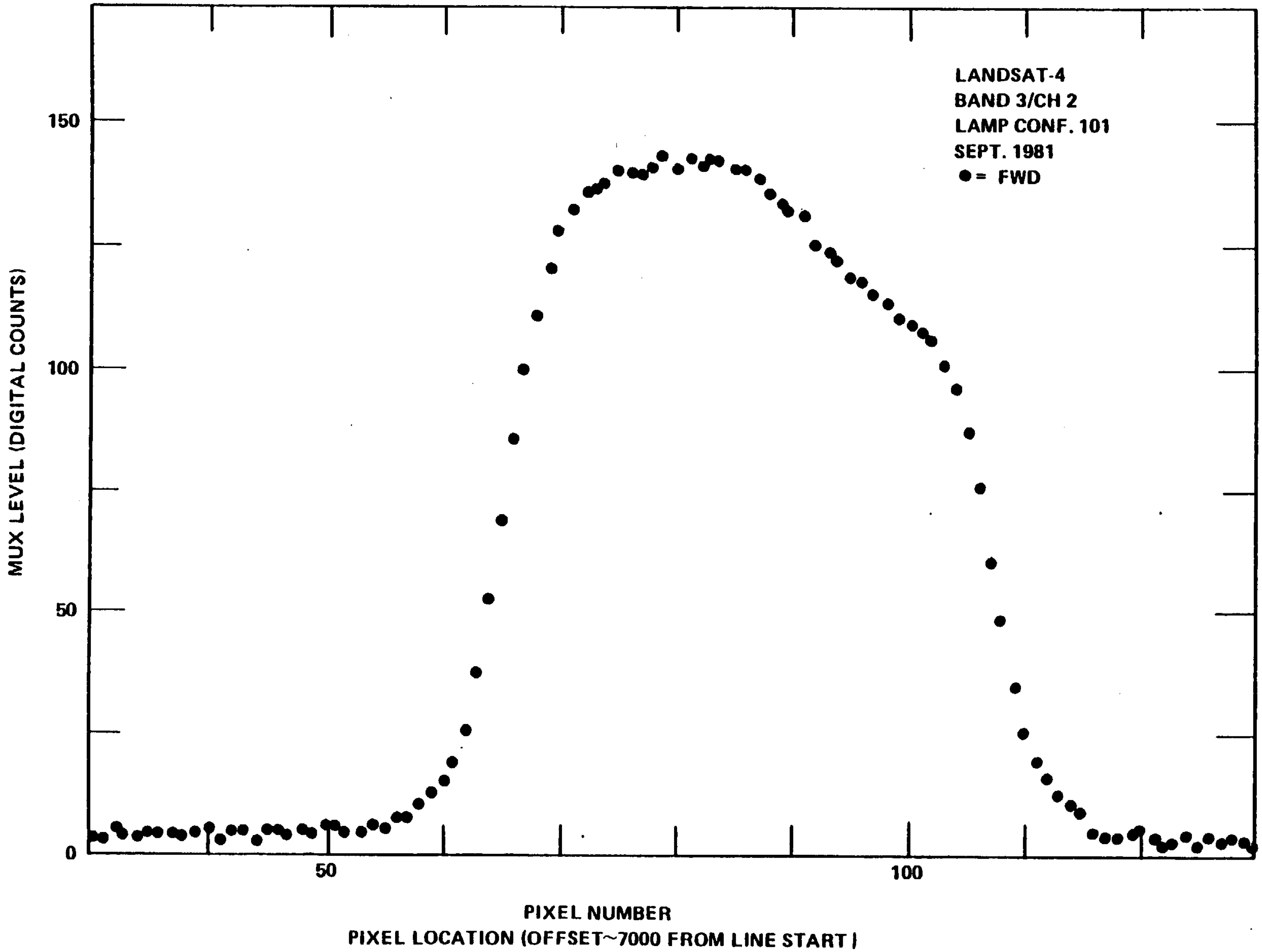


Figure 7c. Typical Calibration Pulse

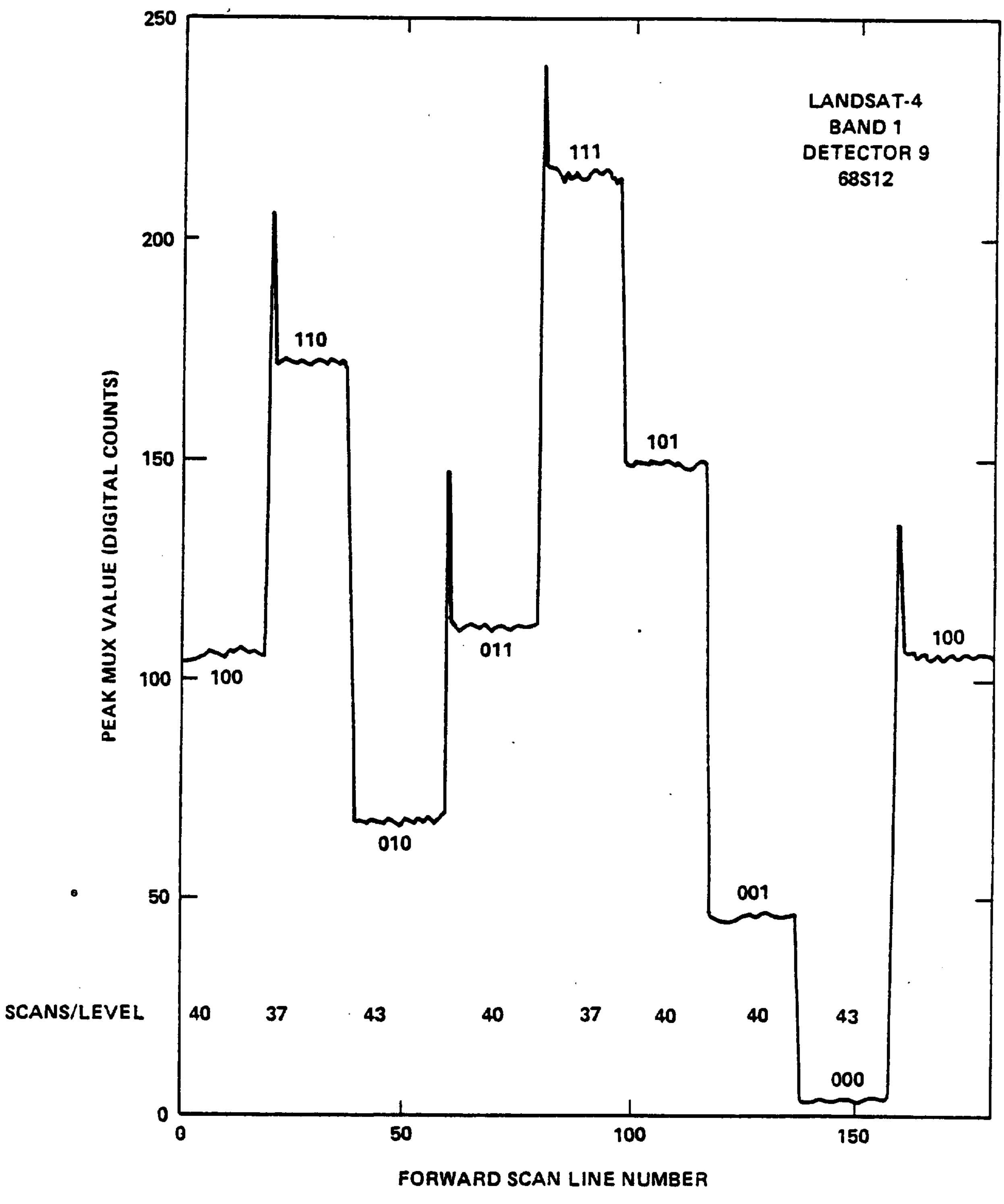


Figure 7d. TM/PF Internal Calibrator Lamp Sequence Showing Lamp Turnon Overshoot

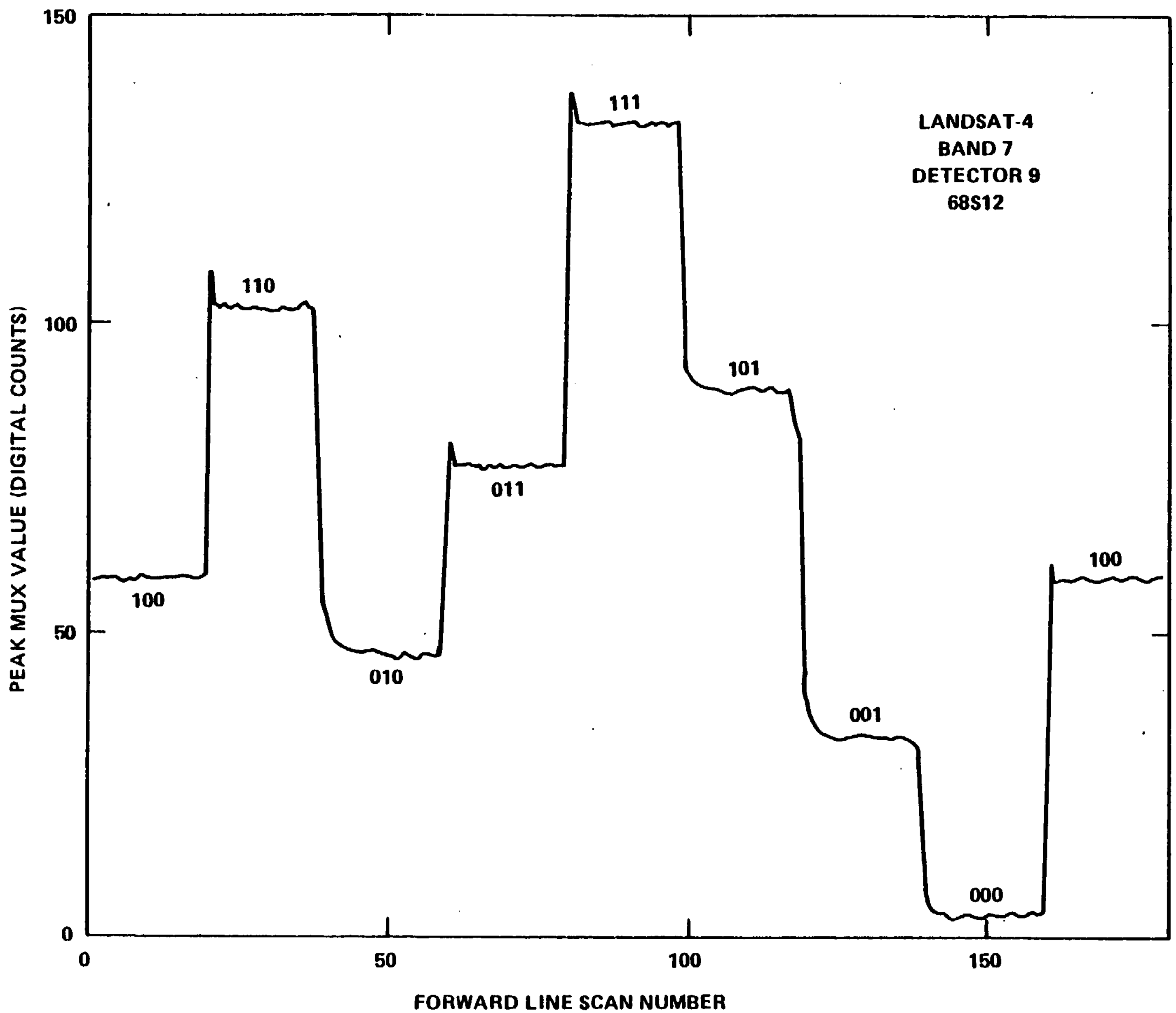


Figure 7e. TM/PF Internal Calibrator Lamp Sequence Showing Lamp Overshoot and Thermal Relaxation

are not available within PCD.) In the automatic mode, the calibration lamp ON/OFF monitors indicate whether or not each lamp is enabled for operation under sequencer control.

When the internal calibration lamps are operated in the backup mode, changes in lamp configuration are controlled directly by ground command. In this mode, the calibration lamp ON/OFF monitors indicate the lamp configuration. NASA has no plans to operate the TM in this backup mode.

5.3.2 DC Restore System

DC restore is a technique for minimizing the effects of low frequency noise and drift. A zero-radiance level is applied to the sensors during shutter obscuration to develop a zero-clamp level for the analog-to-digital circuitry. This zero-clamp level is fractionally updated before each scan to a nominal level of 3 digital counts. The zero-clamp level observed during the shutter-closed period should be considered representative of a sensor black-level output during imaging (although detector noise may result in output values below the dc restore adjustment value when viewing a zero-radiance scene).

The zero-radiance condition is established when the shutter blocks the normal optical path for each detector, and is present throughout the obscuration period except during the calibration pulse. Shutter obscuration occurs approximately 1.2 milliseconds after EOL on both forward and reverse scans, and continues for approximately 8.3 milliseconds. Adjustment of the zero-clamp level begins approximately 2.2 milliseconds after EOL on forward scans, or approximately 5.4 milliseconds after EOL on reverse scans, and continues for approximately 3.1 milliseconds.

5.3.3 Thermal Band Radiometric Calibration System

A temperature-controlled blackbody and a temperature-measured shutter surface provide the calibration reference points for the four Band 6 detectors. Band 6 detectors view the temperature-measured shutter surface during the dc-restore calibration period and the temperature-controlled blackbody during the calibration period of each mirror scan. (Refer to Table 7 for the location of these two periods in the TM forward and reverse scans.) The calibration shutter and blackbody temperatures are measured and inserted in mission telemetry (minor-frame words 49 and 47, respectively - see Table 13), and in the payload correction data (PCD) TM housekeeping telemetry (reference 5.4.7.2.k). Absolute calibration will be necessary for the thermal IR channel to account for the blackbody shading factor. Compensation for temperature drift and possible emissivity variations is expected to be required throughout the mission. A further description of the thermal band radiometric calibration procedure is provided in Appendix G.

5.4 TM OUTPUT FORMAT

The TM output is an 84.903 ±0.080 Mbps nonreturn-to-zero mark (NRZ-M) serial bit stream. This signal employs differential transmission and has redundant outputs for the X-band and Ku-band communication channels. Eight TM bits are grouped to form a word; words are grouped into minor frames; and minor frames are used to form major frames. Each major frame contains all data applicable to the one sweep (71.46 milliseconds) of the scan mirror. The output format is shown in Figure 8 and is described in the following subparagraphs.

Several "key parameters" are commonly used terms in Landsat image processing. Brief definitions follow:

a. Swath Angle--The object space angle of scan mirror travel during the active scan time.

b. Scan Rate--The angular scan velocity of the scan mirror.

c. Dwell Time--Detector sample time for Bands 1 through 5 and 7.

d. Line Length--The number of detector sample times during the active scan time.

e. Filter Frequency--The nominal bandwidth of the detector presample filter.

f. Data Rate--The TM output bit rate.

g. IFOV--Instantaneous field of view.

h. Scan Period--The time of a complete scan cycle including one forward and one reverse scan.

i. Scan Frequency--The reciprocal of the scan period.

j. Active Scan Time--The time required for the scan mirror to travel from its start scan position to its end scan position.

k. Turnaround Time--The time from end-of-scan to the next start-of-scan, during which scan mirror motion reverses direction.

The nominal values of these key parameters are as follows:

a. Swath angle: 15.390 degrees (nominal)

b. Scan rate: 4.42191 rad/sec (nominal object space)

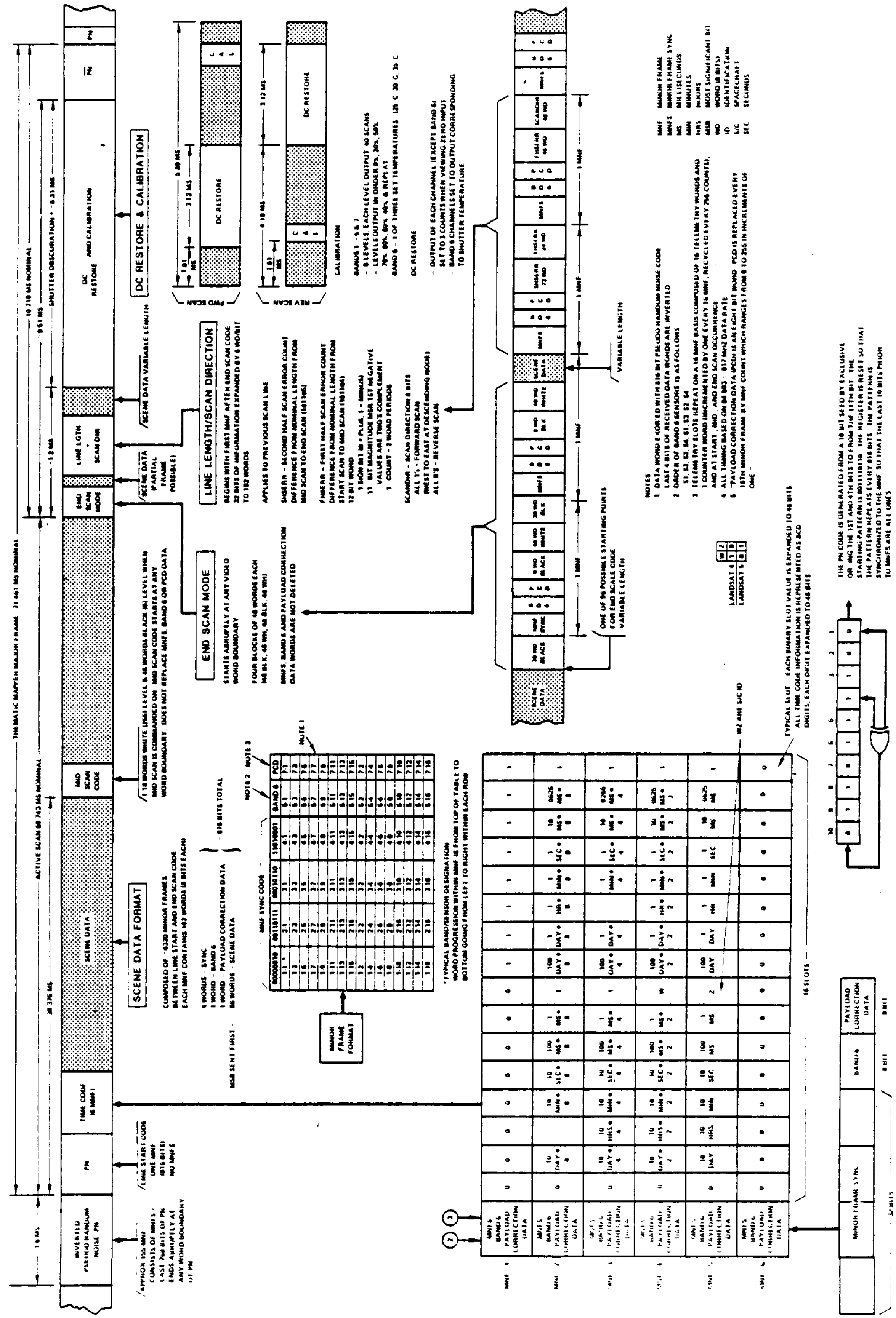


Figure 8. Thematic Mapper Data Format

c. Dwell time: 9.611 μsec

d. Line length: 6320.3985 IFOV's (nominal)

e. Filter frequency: 52.02 kHz

f. Data rate: 84.903 ±0.080 Mbps

g. IFOV Bands 1 through 5 and 7 (nominal values) = 42.5 μrad; Band 6 = 170.0 μrad

h. Scan period: 142.922 msec (nominal)

i. Scan frequency: 6.9968 Hz (nominal)

j. Active scan time: 60,743.013 microseconds (nominal)

k. Turnaround time: 10.719 msec (nominal)

Figure 9 details the pseudorandom noise code for the TM scan-line start.

All words in the format, except for minor-frame sync, scan-line start, and "not-pseudonoise" ($\overline{PN}$), will have the last four bits inverted and will then be PN-encoded.

5.4.1 Major Frame Sync

The major-frame sync is referred to herein as the scan-line start (SLS). The SLS begins with the third word after the word in which the SLS pulse from the scanner has been sensed. The SLS consists of 816 bits of PN code generated from a 10-bit register so that the last 10 bits of the SLS are 10 logical ones. (See paragraph 5.4.5, PN Encoding.) The actual bit pattern is shown in Figure 9. The SLS preempts all data; however, word sync is maintained from scan to scan. The SLS words are not PN-encoded.

5.4.2 Major-Frame Format

Since each TM word major frame contains the data relative to a single mirror sweep, the frame is of variable length. The major frame length during normal operations will be 7435.3 ±30 minor frames. Major frames are partitioned into minor frames. The major-frame formats are defined in Tables 6 and 7. (See Table 8 for the time-code format and Figure 8 for the TM data format.)

5.4.3 Minor-Frame Format

Each scan is divided into minor frames of 102 words of 8 bits each. The format for a single minor frame is shown in Figure 10. All minor frames except the last one are composed of 816 bits. The last minor frame of any major frame may contain any integral number of 8-bit words up to the full 102.

```
  1   00111101101101000000010100001011010101000111110111
 51   10010010110000001001100100010100011011011100000111
101   10001110111111110010000110001011011101000110101011
151   00111100101101100100000100010010011000000101100010
201   10011101100111000101111110101000101110110101100001
251   10011011010100000111010011110100110101001001110000
301   011111001110011011111010001010101101111100001001110
351   10001110101111101101001000010000101001010110001110
401   01111111011000010001101001110010011110000110111011
451   00011000111101111110100100101000000110100011000111
501   01001011010001000101100110100101001000110000111011
551   01111000001011100101011100111011101110011001110101
601   01110111101100101000100110110001000011100101111100
651   10100110011001010101001111110011000110101111001101
701   01101001100010010111000010111101010101111111111010
751   00001010100101111000101011110111010100110111001000
801   1110001111111111
```

Figure 9. Pseudonoise Code for Thematic Mapper Scan-Line Start, Data Encoding and Complement of the Epilog

Table 6
Thematic Mapper Major-Frame Format

Nominal Number of Minor Frames Required	Starting Minor Frame	Data Type
1	0	Major-frame sync code
6	1	Time code
3152 ±10	7	Scene
2	**	Midscan code*
3159 ±10	3161 ±10	Scene
3 +0, -1	6320 ±20	End-scan code--START
	End scan +2	End-scan code--END
	End scan +3	Line length
155 ±30	End scan +960	Postamble--START
	7435.3 ±30	Postamble--END

*If command ON, otherwise replaced with scene data.
**Approximately at center of scan.

Table 7
Thematic Mapper Data Format
(From end of scan to end of turn-around period)

	Forward Scan West to East at Descending Node		Reverse Scan East to West at Descending Node	
Event	Start Minor Frame Count	End Minor Frame Count	Start Minor Frame Count	End Minor Frame Count
End Scan	6320 ±20	End scan +2	6320 ±20	End scan +2
Line Length and Scan Direction	End scan +3	End scan +4	End scan +3	End Scan +4
Shutter Obscuration	6445 ±50	Obscuration Start +865	6445 ±50	Obscuration Start +885
DC Restore	End scan +230	End Scan +555	End Scan +560	End Scan +885
Calibration	Obscuration Start +583	Obscuration Start +703	Obscuration Start +75	Obscuration Start +195
$\overline{PN}$	End scan +960	7435.3 ±30	End Scan +960	7435.3 ±30

Note: The start and end times are nominal times.

Table 8
Thematic Mapper Time-Code Format

	A	B	C	D	E	F
1	0	0	0	0	0	0
2	0	10 D(8)	10 D(4)	10 D(2)	10 D(1)	0
3	0	10 H(8)	10 H(4)	10 H(2)	10 H(1)	0
4	0	10 M(8)	10 M(4)	10 M(2)	10 M(1)	0
5	0	10 s(8)	10 s(4)	10 s(2)	10 s(1)	0
6	0	100 ms(8)	100 ms(4)	100 ms(2)	100 ms(1)	0
7	0	1 ms(8)	1 ms(4)	1 ms(4)	1 ms(1)	0
8	0	X1	X2	X3	X4	0
9	1	100 D(8)	100 D(4)	100 D(2)	100 D(1)	0
10	1	1 D(8)	1 D(4)	1 D(2)	1 D(1)	0
11	1	1 H(8)	1 H(4)	1 H(2)	1 H(1)	0
12	1	1 M(8)	1 M(4)	1 M(2)	1 M(1)	0
13	1	1 s(8)	1 s(4)	1 s(2)	1 s(1)	0
14	1	10 ms(8)	10 ms(4)	10 ms(2)	10 ms(1)	0
15	1	1/2 ms	1/4 ms	1/8 ms	1/16 ms	0
16	1	*	*	*	*	0
Output Sequence: A1-A16, B1-B16, C1-C16, D1-D16, E1-E16, F1-F16						

D - Day
H - Hours
M - Minutes
s - Seconds
ms - Milliseconds

* = Spares (set to "1")
( ) = BCD weight
X(1-4) = Spacecraft ID as follows:
1110 = Landsat-4
1101 = Landsat-5

5.4.4 Minor-Frame Sync

The minor-frame sync is a 32-consecutive-bit sync word. The first bit of the first minor-frame sync occurs immediately following the 816-bit SLS and is repeated every 816 bits until the next SLS reinitializes the sequence. The sync word is not PN-encoded and has been selected to maximize the opportunity to correct for bit slippages. The sync word can be interrupted by the SLS at the 8-bit word boundaries. The selected bit pattern for the sync word can be represented as the hexadecimal number 02 37 16 D1.

5.4.5 PN Encoding

All TM data except for: (1) major-frame sync, (2) minor-frame sync, and (3) postamble data are PN-encoded. Encoding is accomplished by inverting the 4 least significant bits (LSB's) of each

SYNC	SYNC	SYNC	SYNC	BAND 6	PCD
B1 S1	B2 S1	B3 S1	B4 S1	B5 S1	B7 S1
B1 S3	B2 S3	B3 S3	B4 S3	B5 S3	B7 S3
B1 S5	B2 S5	B3 S5	B4 S5	B5 S5	B7 S5
B1 S7	B2 S7	B3 S7	B4 S7	B5 S7	B7 S7
B1 S9	B2 S9	B3 S9	B4 S9	B5 S9	B7 S9
B1 S11	B2 S11	B3 S11	B4 S11	B5 S11	B7 S11
B1 S13	B2 S13	B3 S13	B4 S13	B5 S13	B7 S13
B1 S15	B2 S15	B3 S15	B4 S15	B5 S15	B7 S15
B1 S2	B2 S2	B3 S2	B4 S2	B5 S2	B7 S2
B1 S4	B2 S4	B3 S4	B4 S4	B5 S4	B7 S4
B1 S6	B2 S6	B3 S6	B4 S6	B5 S6	B7 S6
B1 S8	B2 S8	B3 S8	B4 S8	B5 S8	B7 S8
B1 S10	B2 S10	B3 S10	B4 S10	B5 S10	B7 S10
B1 S12	B2 S12	B3 S12	B4 S12	B5 S12	B7 S12
B1 S14	B2 S14	B3 S14	B4 S14	B5 S14	B7 S14
B1 S16	B2 S16	B3 S16	B4 S16	B5 S16	B7 S16

B = BAND NUMBER S = SENSOR NUMBER

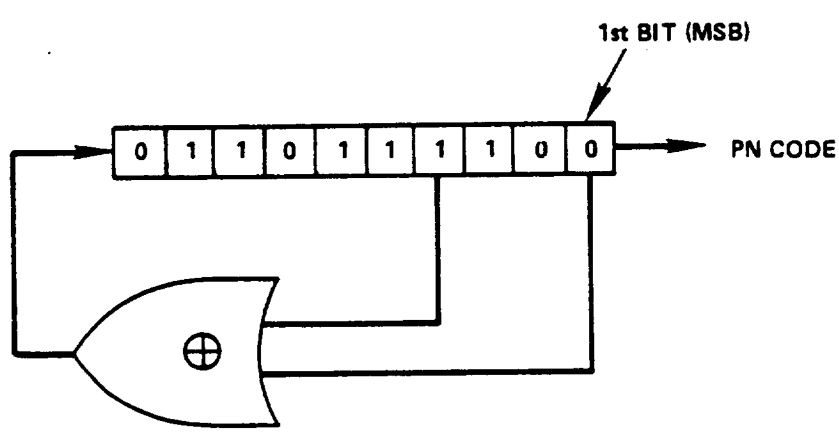
Figure 10. TM Minor-Frame Format

8-bit word and exclusive ORing the resultant word with a pseudorandom noise (PN) code. The PN code (Figure 9) is generated from a 10-bit seed word (0011 1101 10) by exclusive ORing the 1st and 4th bits to create the 11th bit, as shown below. The resultant 1024-bit repeating code is truncated (reset to the seed word) each minor frame so that the last 10 bits of the code used in each minor frame are "1's." Note that, since the first 4 words (32 bits) of each minor frame are minor-frame sync and not encoded, the first bit used in encoding is the 33rd bit of the sequence produced by the generator shown. The generator also produces the PN code used for major-frame sync and the inverted PN code used as postamble.

The PN code generator is reset to a fixed value (00 1111 0110) for the start of scan line and for the start of each minor frame thereafter. This starting code, along with all other codes produced by the PN code generator, are shown in Figure 9. Note that the first 32 bits of each minor frame are not PN-encoded. (See Figure 10.) PN encoding is performed only on bits 33 through 816 of each minor frame. The PN code bits (Figure 9) are exclusive ORed with corresponding video data word bits (the last 4 bits of each video word are inverted before the exclusive OR process is performed). The PN-encoded data are transmitted to ground, most significant bit (MSB) first. The PN inverse code consists of 4 words of minor-frame sync, Band 6 sensor word and PCD word (PN-encoded), followed by 768 bits of inverted PN code (PN bits 49 to 816 inverted) repeated continuously for approximately 1 millisecond. Refer to Table 7 for the timing of PN inverse code.

5.4.6 Band 6 Sensor Word

The outputs of the 4 thermal-band detectors of Band 6 appear in sequential minor frames as the first 8 bits immediately following the minor-frame sync. The signal from Detector 1 of Band 6 occurs in the first minor frame after SLS and every fourth minor frame thereafter. The output sequence is Detector 1, Detector 3, Detector 2, then Detector 4. Band 6 sensor words are PN-encoded.



5.4.7 Payload Correction Data

The PCD contain all data required by ground stations for correcting TM sensor data. The data sources, data, and timing associated with their collection, formatting, and transmission to ground stations are provided in this section for the TM payload data stream. The PCD are transmitted to ground stations by a 32-kbps digital signal modulated on the S-band carrier and within the TM payload data stream, carrying the following types of data:

- Angular Displacement Sensor (from the Angular Displacement Sensor Assembly-ADSA)
- ADS Temperature (from ADSA)
- Gyro Data (from OBC)
- Gyro Drift Data (from OBC)
- Attitude Estimate (from OBC)
- Ephemeris (from OBC)
- TM Housekeeping Data (from OBC)
- Spare Housekeeping Data (from OBC)
- Spacecraft Time Code (from the Power Distribution Unit-PDU)
- MUX Status (generated in the PCD formatter)
- A/D Ground Reference (from ADSA)
- Sync (generated in the PCD formatter)
- Major Frame Identification - MFID (generated in the PCD formatter)
- Telemetry Frame Correlation (generated in the PCD formatter)

The PCD contain information from many sources, including a 2- to 125-Hz bandwidth jitter measuring sensor. The jitter information is derived from a three-axis angular displacement sensor (ADS) that is mounted on the TM instrument. Calibration of this sensor is based on prelaunch test results. The ADS output will be quantized to 12 bits per axis. The PCD are formatted, subsequently multiplexed onto a 32-kbps digital S-band data link, and inserted in the TM payload data stream.

The sixth word in each TM minor frame contains either 8 bits of PCD or, in every 16th minor frame, a minor-frame counter number. The minor-frame count commences with a count of "zero" at minor-frame 16 (the 16th minor frame of video after SLS) and is incremented by one and inserted every 16 minor frames thereafter. This counter also resets to "0" beginning in the 16th minor frame after end-of-line (and after midscan, if in use). The PCD "word" is either SYNC, FILLER, or DATA. (See Paragraph 5.4.7.1.) The words are output in the order FILLER, SYNC, DATA, DATA, DATA, FILLER, FILLER FILLER... SYNC words are hexidecimal 16's (00010110) and FILLER words are hexidecimal 32's (00110010). DATA words are repeated twice (three words total) and represent eight unique bits of PCD. Approximately 20-21 filler words are required between each data set. PCD and minor-frame counter words are PN-encoded, and the left-most bit of MSB is output first. PCD word sync will be repeated every 24-25 words in the unpacked PCD format (i.e., after minor-frame counter removal).

5.4.7.1 Packed and Unpacked PCD Formats--The PCD, which are asynchronous with TM data, are generated at 4 kbytes/sec. The TM requests a PCD word for 15 of every 16 minor frames, or at a rate of 97,545 Hz. As a result, the PCD transmitted in word 6 of the wideband TM payload data stream are in an unpacked format. Filler words are used to rate buffer the PCD 4 kbytes/sec generation rate up to the 97,545 Hz TM PCD word request rate. The number of filler words required to accomplish this rate buffering will vary. The user will be required to synchronize on the unpacked format data stream, extract the data words, perform a majority vote on the validity of the three identical data words to select one of the three words, and pack the selected data words into a buffer. The unpacked PCD format (TM minor-frame word 6) must be reformatted to match the packed PCD format by the user before the data can be extracted. The processing necessary to transform the PCD data in word 6 of the TM minor frames to the packed PCD format is shown in Figure 11.

a. Unpacked PCD format (TM minor-frame word 6)

TM Payload Word 6 (PCD word content)		Value
FILLER		HEX 32 (00110010)
SYNC		HEX 16 (00010110)
DATA	one 8-bit data value repeated twice	
DATA		
DATA		
FILLER		HEX 32
FILLER		HEX 32
FILLER		HEX 32
.		
.		
.		

It should be noted that PCD are replaced in minor frames 16, 32, 48 ... by minor-frame ID words.

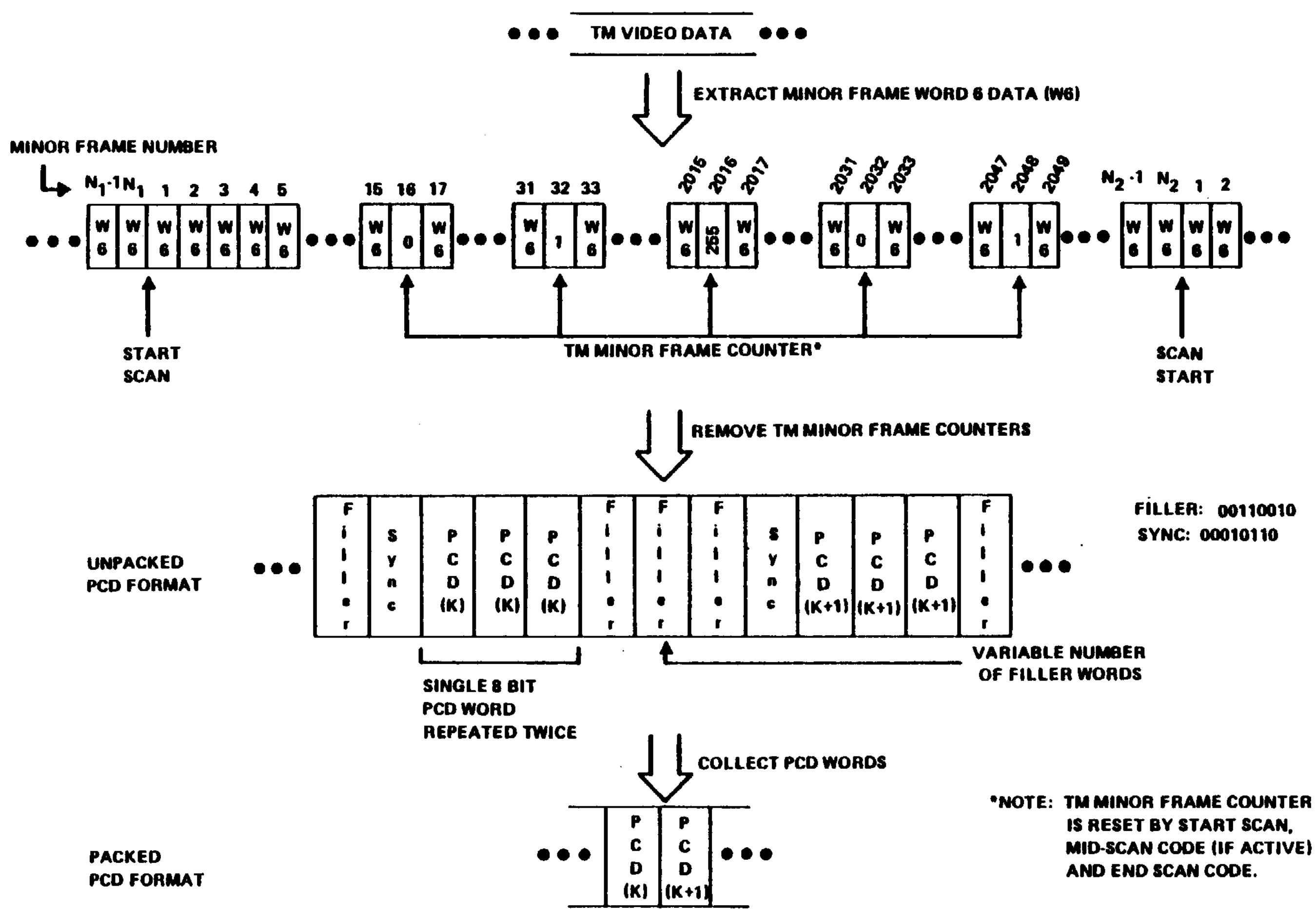


Figure 11. PCD Extraction from TM Video Data

b. Packed PCD format (by user)

Cycle length: 4 major frames
Subcom sequence length: 4 major frames
Major-frame length: 128 minor frames
Minor-frame length: 128 words, 8 bits/word (Figure 12)

(1) PCD cycle format (Figure 12)

(2) PCD major-frame format (Figures 13 and 14)
Sync word hexidecimal FAF320

(3) PCD subcom (Figures 15, 16, and 17)

5.4.7.2 Data and Timing--The timing of all PCD data items is given, referenced to the PCD time code for the PCD cycle in which the data item appears. The PCD time code is described under Section g. of this paragraph.

a. ADSA--The Attitude Displacement Sensor Assembly (ADSA) consists of three nominally orthogonal ADS sensors. The ADSA is mounted on the TM telescope. Each axis of the ADSA will be sampled every 2 milliseconds. The sample will be converted to a 12-bit integer word and inserted in two consecutive words of the format, with the four MSB's of the first word set to zero.

Digital count 0 is maximum positive angular displacement, and digital count 4095 is maximum negative angular displacement. The LSB of each count is $250/2^{11}$ microradians. The nominal zero angular displacement output of the ADSA is 2048 $\pm$50 counts. (The $\pm$50 count variation is considered to be of negligible magnitude.)

Each ADSA axis is sampled every 0.002 second. There are 8192 samples of each ADSA axis in a PCD cycle. The sample timing is given below.

Let the samples of any one axis appearing in a PCD cycle be numbered N = 0,1,2,...,8191. Then the time for each sample is defined relative to the PCD time code of the PCD cycle by:

ADSA AXIS	SAMPLE TIMES
1	PCD Time Code + (2N + 3/8) milliseconds
2	PCD Time Code + (2N + 7/8) milliseconds
3	PCD Time Code + (2N + 3/8) milliseconds

Each axis of the ADSA has a nominal 2.0 to 125.0 Hz bandwidth. The exact transfer function to rotational motion is given in Appendix C.

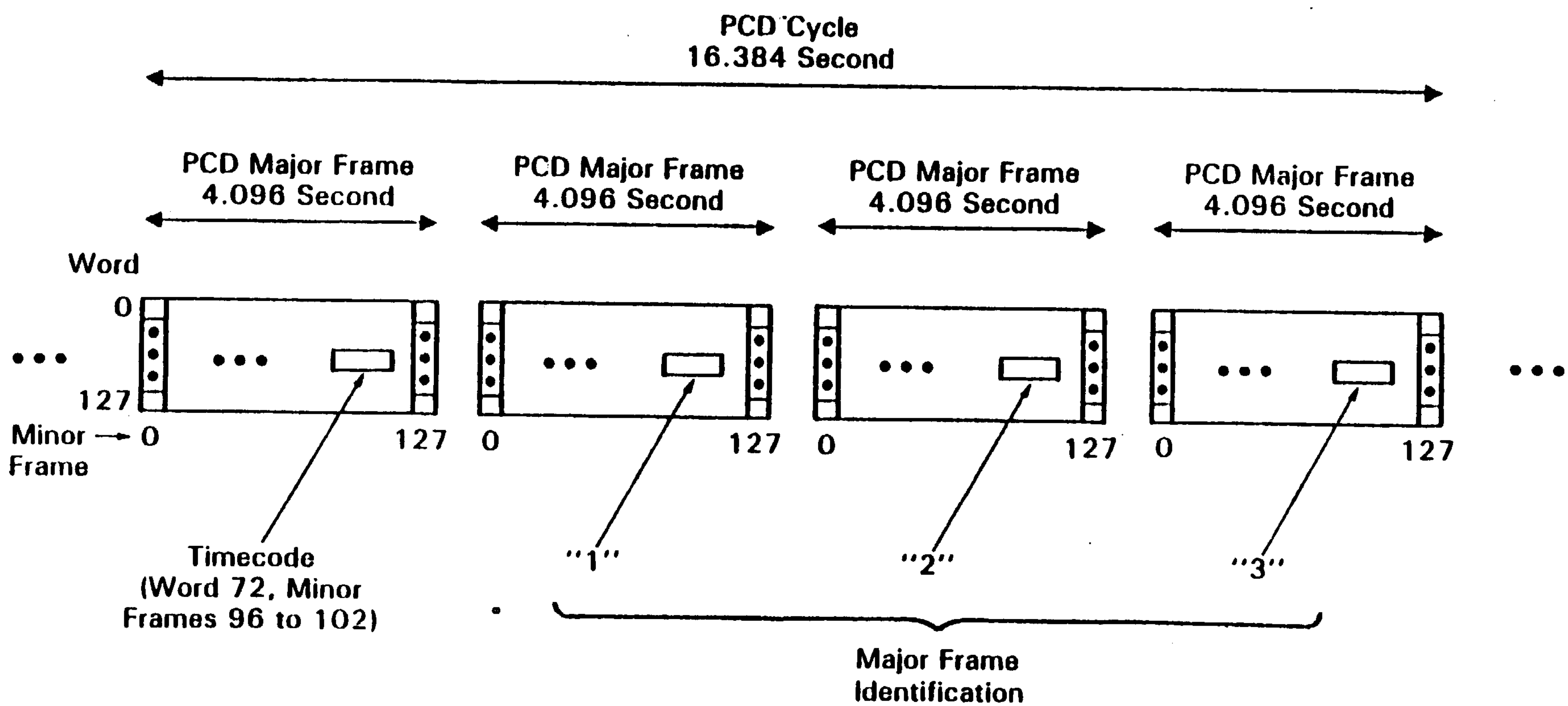


Figure 12. Payload Correction Data - Cycle Format

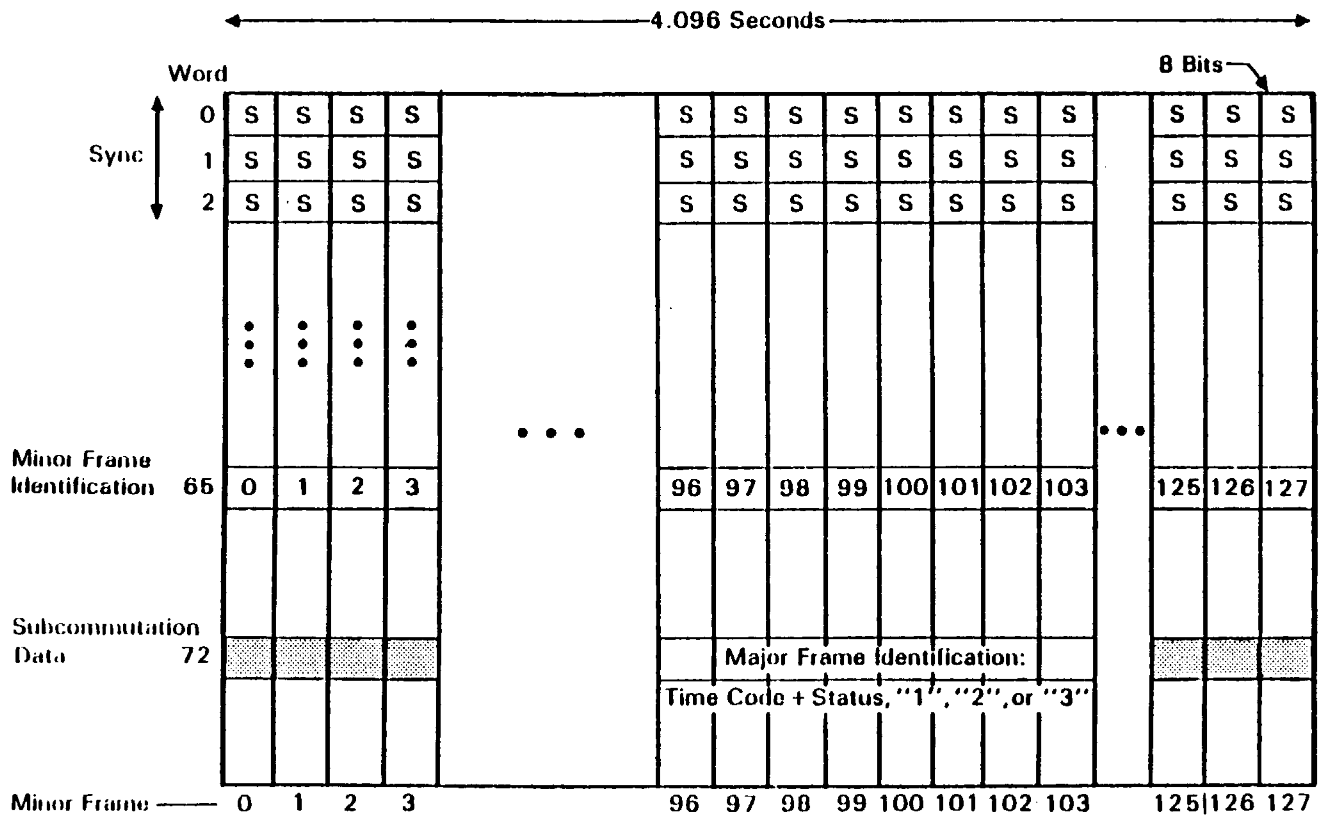


Figure 13. Payload Correction Data - Major Frame Format

32 msec (128 WORDS)

SYNC		0,1,2
ADS	1*	3,4
ADS	2	5,6
ADS	3	7,8
		9
		10
ADS	1	11,12
ADS	2	13,14
ADS	3	15,16
GYRO (FIG 18)		17
		18
ADS	1	19,20
ADS	2	21,22
ADS	3	23,24
		25,26
ADS	1	27,28
ADS	2	29,30
ADS	3	31,32
GYRO (FIG 18)		33
		34
ADS	1	35,36
ADS	2	37,38
ADS	3	39,40
		41,42
ADS	1	43,44
ADS	2	45,46
ADS	3	47,48
GYRO (FIG 18)		49
		50
ADS	1	51,52
ADS	2	53,54
ADS	3	55,56
		57,58
ADS	1	59,60
ADS	2	61,62
ADS	3	63,64

WORDS IN MINOR FRAME

MFID		65
ADS	1	66,67
ADS	2	68,69
ADS	3	70,71
SUB COMM (FIG 15)		72
		73
ADS	1	74,75
ADS	2	76,77
ADS	3	78,79
		80
GYRO (FIG 18)		81
ADS	1	82,83
ADS	2	84,85
ADS	3	86,87
		88,89
ADS	1	90,91
ADS	2	92,93
ADS	3	94,95
		96
GYRO (FIG 18)		97
ADS	1	98,99
ADS	2	100,101
ADS	3	102,103
		104,105
ADS	1	106,107
ADS	2	108,109
ADS	3	110,111
		112
GYRO (FIG 18)		113
ADS	1	114,115
ADS	2	116,117
ADS	3	118,119
		120,121
ADS	1	122,123
ADS	2	124,125
ADS	3	126,127

WORDS IN MINOR FRAME

* 1 = roll (x), 2 = pitch (y) and 3 = yaw (z)

Figure 14. PCD Minor-Frame Format

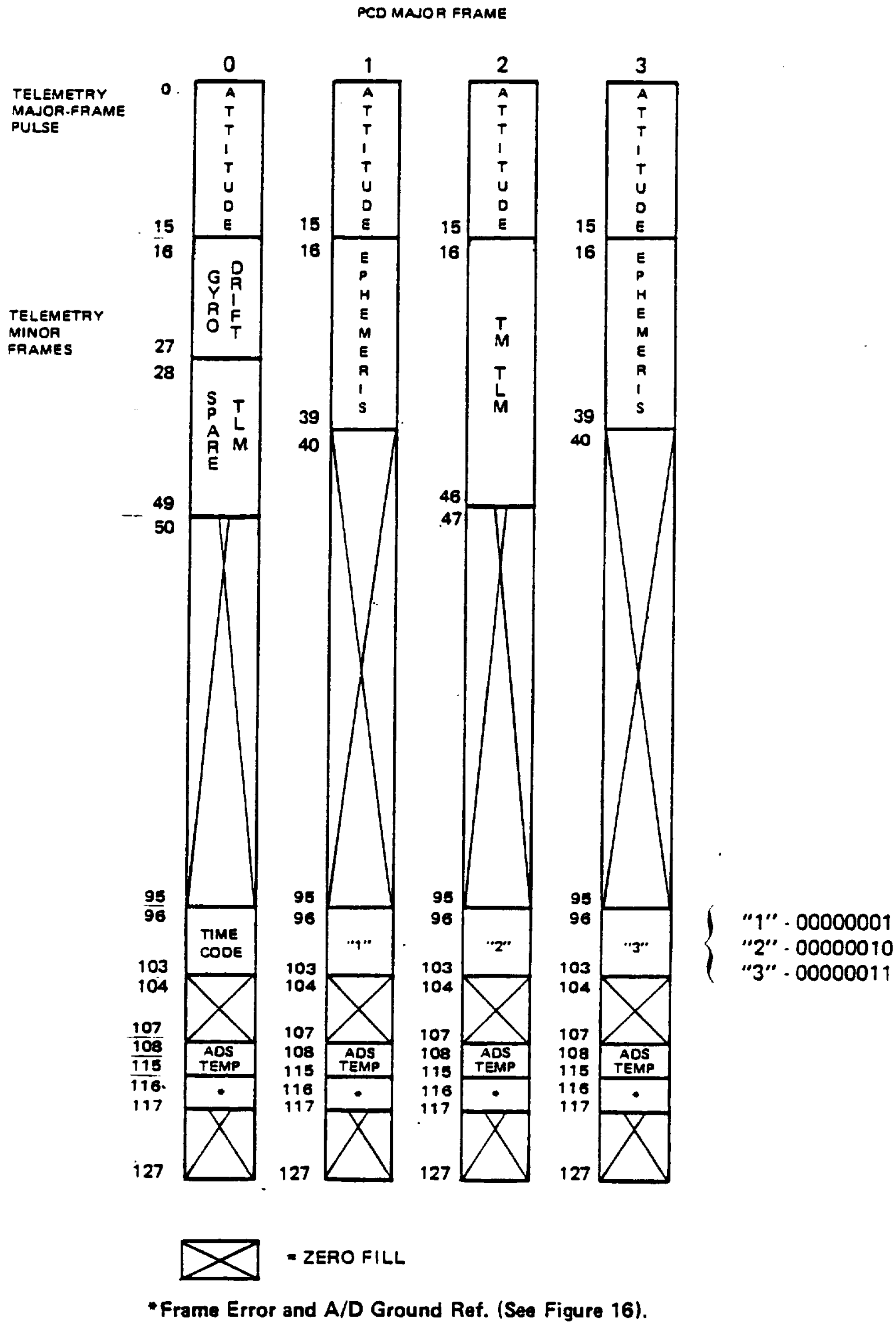


Figure 15. Subcommutation Data (Word 72)

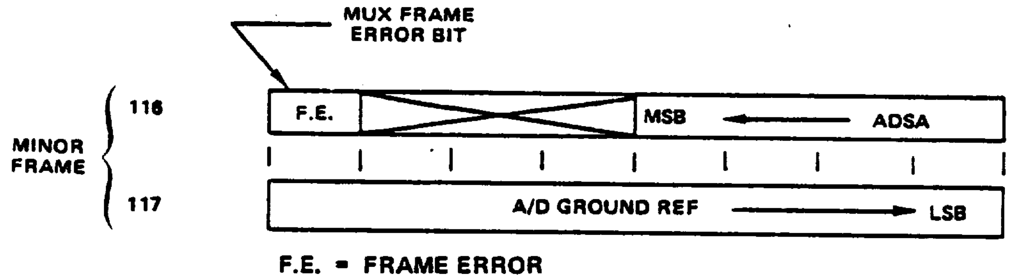


Figure 16. Frame Error and A/D Ground Reference

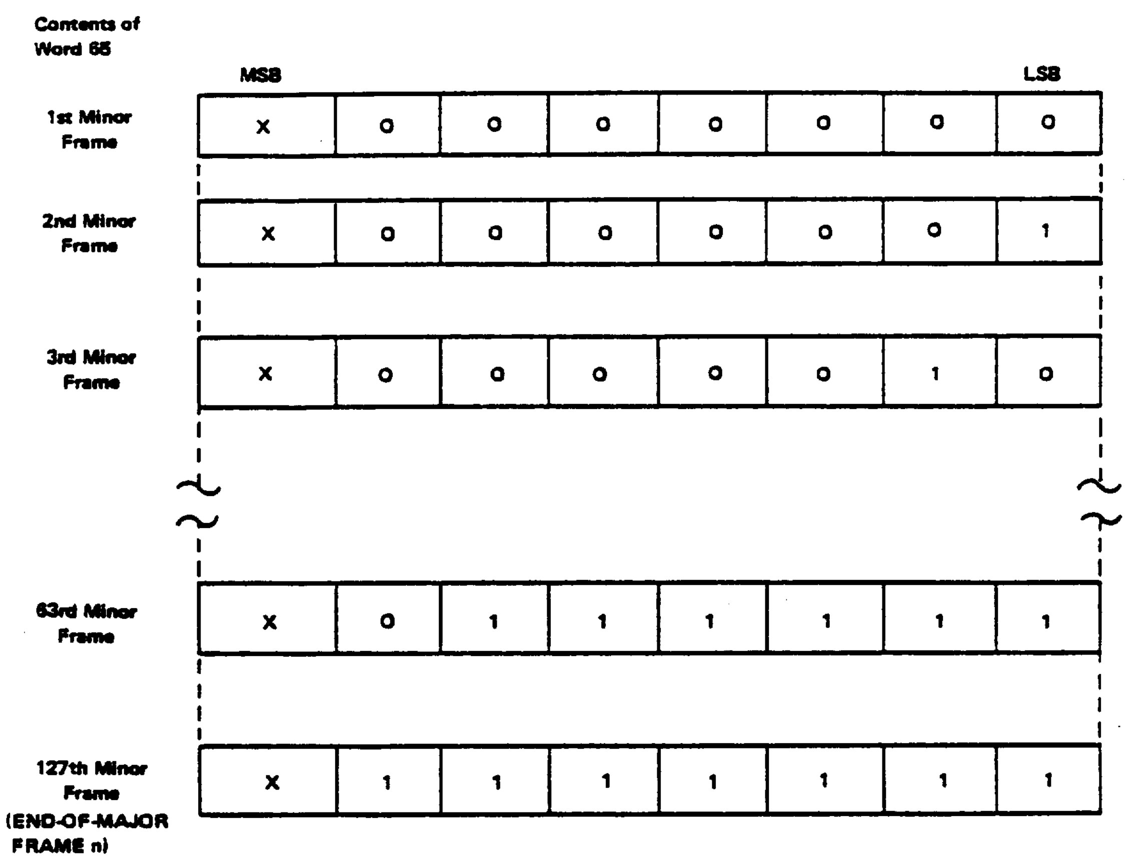


Figure 17. Frame Counter Identification Bit Pattern

The nominal relative alignment between the ADS and the spacecraft is $X_{ADS} = X_{S/C}$ where Y_{ADS} and Z_{ADS} are rotated CCW nominally 20° about $X_{S/C}$. Appendix F defines the exact alignment.

No attempt to calibrate the ADSA postlaunch is planned. Predicted jitter levels indicate the need for all ADS data. If this analysis proves to be too conservative, less use of ADSA data may be possible in routine processing. NASA has designed its processing to use all ADSA data.

b. ADSA Temperature--Up to four ADSA-related temperatures will be sampled once a PCD major frame (4.096 sec). Each sample will be converted into 2 8-bit words with the first 4 bits of the first word set to zero. As before, the data will be sampled in the word time preceding the first data word. That is:

	Minor Frame	Data Word	Sample Time (word)
Temperature 1	108-109	72	71 (108)
Temperature 2	110-111	72	71 (110)
Temperature 3	112-113	72	71 (112)
Temperature 4	114-115	72	71 (114)

ADSA temperature is in degrees centigrade with an LSB weight of 0.01221°C. Zero counts corresponds to +50°C and 4095 counts corresponds to 0°C.

Temperature compensation of ADSA and DRIRU data does not appear to be necessary and is not planned at this time.

c. Gyro Data--Each axis of both dry rotor inertial reference units (DRIRU's) is sampled by the OBC every 64 milliseconds; one data value for each axis is provided in PCD. The data will consist of a 24-bit word for each axis (a total of 72 bits). Figure 18 shows the format of the gyro data in the PCD. Each sample consists of three 8-bit bytes. The three bytes must be assembled into the 24-bit word. The data are in 2's complement format with the most significant bit first.

About each axis, the DRIRU generates a signed pulse for each 0.05 arc-sec of angular motion. A positive pulse increments a 24-bit register and a negative pulse decrements the register. A positive pulse is generated by a negative rotation about the gyro axis. The OBC samples this register every 64 milliseconds.

Pitch orbital motion and gyro drift cause the register to periodically overflow. The register is reset to zero when its value is positive $2^{23}-1$ and a positive pulse is received

Minor Frame	Word in Minor Frame					
	17	33	49	81	97	113
0	⊠	⊠	⊠	1_1	1_2	2_1
1	1_3	2_2	2_3	3_1	3_2	3_3
2	⊠	⊠	⊠	1_1	1_2	2_1
3	1_3	2_2	2_3	3_1	3_2	3_3
⋮	⋮	⋮	⋮	⋮	⋮	⋮

⊠ = No Data

1_n = X axis (roll) byte n
2_n = Y axis (pitch) byte n
3_n = Z axis (yaw) byte n

Three eight-bit-bytes (n = 1 - 3) are required per axis. The MSB is output first.

Figure 18. Gyro Data

or when its value is negative 2^{23} and a negative pulse is received.

Each DRIRU axis has a nominal 0-2 Hz bandwidth. The exact transfer function is given in Appendix C.

There are 256 samples of each DRIRU axis during a PCD cycle. Each axis is sampled at the same time. The sample timing is as follows:

> Let the gyro samples for any one axis appearing in a PCD cycle be numbered N = 0,1,...,255. Then the time for each sample is the PCD time code plus (64N - 28) milliseconds.

During ground processing, DRIRU data is compensated by correcting the sign, scaling and rotating the data into the ACS reference axes. Appendix F defines the relationship between the DRIRU sensing axes and the ACS reference axes.

d. Gyro Drift Data--The drift calculation is performed by the OBC. Gyro drift parameters are updated asynchronously based on star sightings at up to once per minute. When a gyro drift value is observed to change, the estimate was changed at the PCD time code for the cycle minus 14.337 seconds. The data consist of a 32-bit two's-complement value for each axis (THETA BX, THETA BY, THETA BZ - See Table 21).

Gyro drift is calculated in the ACS reference axis coordinate system defined in Appendix F. Gyro drift must be subtracted from the compensated DRIRU data as a correction to calculate spacecraft attitude. The units of gyro drift rate are radians/512 ms. Gyro drift output data (in units of radians/512 ms) are calibrated at an LSB weight of 2^{-47}.

The format and frame position of the gyro drift binary scaled integer data is as follows:

		MSB 2^{-17}			LSB 2^{-47}
		SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
MINOR FRAME	THETA BX	16	17	18	19
	THETA BY	20	21	22	23
	THETA BZ	24	25	26	27

The data will appear in word 72 of minor frames 16 through 27 of PCD major frame zero. (See Figure 13.) Since the data will be sampled every 16.384 seconds, it will repeat at least three times between each calculation.

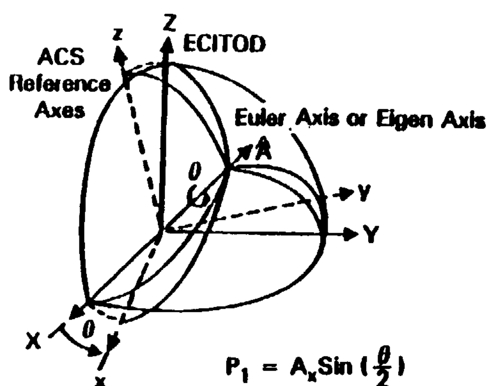
e. Attitude--The OBC calculates a flight segment attitude estimate every 512 milliseconds. The OBC will output one of eight sets of data in telemetry every 4.096 seconds (once a PCD major frame). Attitude is Euler parameters (i.e., EPA1, EPA2, EPA3, EPA4) that specify vehicle attitude relative to Earth-centered inertial frame (nondimensional). $EPA_{1,2,3,4}$ are components of the reference quaternion (as propagated from gyro data) which defines spacecraft attitude. Components 1 through 3 define the Eigen axis of rotation in ECI coordinates, and component 4 defines rotation about that axis, as shown in Figure 19.

Euler double precision words (36 bits) are compressed and scaled to 32 bits, 2's complement binary form as follows:

	← 32 BITS →			
	MSB 2^0			LSB 2^{-30}
BIT ORDER	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
BYTE ORDER	1	2	3	4

- Quaternion Estimate of Attitude Control System (ACS) Reference Axes (Spacecraft Axes) with Respect to the ECITOD Axes
  - EPA1, EPA2, EPA3, EPA4 Given in Payload Correction Data
  - Estimate Given Every 4.096 Seconds
  - Includes Information from Star Trackers, Gyros and Gyro Drift Estimate
  - Accuracy Better than 0.01 Degrees (1σ)

- Definition



$$P_1 = A_x \mathrm{Sin}\left(\frac{\theta}{2}\right)$$
$$P_2 = A_y \mathrm{Sin}\left(\frac{\theta}{2}\right)$$
$$P_3 = A_z \mathrm{Sin}\left(\frac{\theta}{2}\right)$$
$$P_4 = \mathrm{COS}\left(\frac{\theta}{2}\right)$$
$$P_i = EPA_i * 2^{-30}$$

- Direction Cosines Matrix from the ACS Reference Axes to the ECITOD

$$\begin{bmatrix} P_1^2-P_2^2-P_3^2+P_4^2 & 2(P_1P_2-P_3P_4) & 2(P_1P_3+P_2P_4) \\ 2(P_1P_2+P_3P_4) & -P_1^2+P_2^2-P_3^2+P_4^2 & 2(P_2P_3-P_1P_4) \\ 2(P_1P_3-P_2P_4) & 2(P_2P_3+P_1P_4) & -P_1^2-P_2^2+P_3^2+P_4^2 \end{bmatrix}$$

$$\hat{A} = \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$$ is the Eigen axis

θ is the rotation angle about the Eigen Axis which defines the ACS reference axes

Figure 19. Attitude Data

The four compressed Euler Parameters (EP's) are output in word 72 of minor frames 0 through 15 of each PCD major frame. (See Figure 15.) The output sequence of EPA1 through EPA4 is as follows:

Content	PCD Minor Frame Numbers			
EPA1	0	1	2	3
EPA2	4	5	6	7
EPA3	8	9	10	11
EPA4	12	13	14	15
BYTE ORDER	1	2	3	4

There are four attitude estimates in each PCD cycle. The time associated with attitude data contained within the PCD can be derived from the time code contained in words 96 through 102 of the first PCD major frame in the cycle. The derivation is as follows:

PCD Major-Frame Number	Time Computation
0	PCD time code - 4.096 seconds + 36 milliseconds
1	PCD time code + 36 milliseconds
2	PCD time code + 4.096 seconds + 36 milliseconds
3	PCD time code + 8.192 seconds + 36 milliseconds

In the normal operating mode, the OBC computed attitude is output to provide a low-frequency reference attitude. The 4.096-second sample rate does not support reconstruction of high frequency attitude errors. Gyro data are provided every 64 ms to contain 0-2 Hz frequency data and the ADS data, provided every 2 ms, contain frequencies up to 125 Hz. Since these sensors have different frequency responses, the data must be appropriately compensated to be combined.

f. Ephemeris--This calculation is made by the OBC. In this case, only 1 of 16 data sets will be output in the PCD (i.e., every other PCD major frame - 8.192 seconds).

Ephemeris consists of spacecraft position components (EOGBRF, Table 22) X, Y, and Z in meters and spacecraft velocity components (EGOBVF, Table 22) X, Y, and Z in meters per millisecond. Ephemeris is output as 32-bit binary words defining $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ in Earth-centered inertial true-of-date (ECITOD) coordinates. In the ECITOD coordinate system, the Z-axis is along a line from the center of the Earth coincident with the true Earth spin axis, positive north. The X-axis is along a line from the center of the Earth toward the intersection of the true Equator and true ecliptic of date. The Y-axis completes the right-handed set. (The ECITOD system varies slowly with respect to a truly inertial system due to precession and nutation of the Earth's axis and precession of the plane of the ecliptic. These variations occur slowly enough that the ECITOD system can be considered to be inertial over a span of a few days for attitude control purposes.)

The ephemeris data are 36-bit double precision words that have been compressed to 32-bit, 2's complement form by dropping the second sign bit and the three LSB's. The format of these data is as follows:

<u>Position Components</u>

	MSB 2^{22}			LSB 2^{-8}	
WORD 72	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	
X	16	17	18	19	MINOR FRAME
Y	20	21	22	23	
Z	24	25	26	27	

<u>Velocity Components</u>

	MSB 2^{2}			LSB 2^{-28}	
WORD 72	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	
X	28	29	30	31	MINOR FRAME
Y	32	33	34	35	
Z	36	37	38	39	

The data will appear in word 72 of minor frames 16 through 39 of every other PCD major frame. (See Figure 15.) These major frames will carry the "1" and "3" identifier in place of time code.

There are two ephemeris estimates in each PCD cycle. The time associated with ephemeris data contained within the PCD can be derived from the time code contained in words 96 through 102 of the first PCD major frame in the cycle. The derivation is as follows:

PCD Major-Frame Number	Time Computation
1	time code + 36 milliseconds
3	time code + 8.192 seconds + 36 milliseconds

g. PCD Time Code--Fifty-six bits of spacecraft time code (seven 8-bit words) are inserted in the PCD stream. This code represents the start time for PCD major frame 0 and provides the timing reference for all data in the PCD cycle. The 56 bits of spacecraft time code are subcommutated into word 72 of minor frames 96 through 102 of the first PCD major frame of the PCD cycle. (See Figure 15.) The output sequence for the 56 time-code bits is contained in Table 9.

h. PCD Minor-Frame Sync--The same sync pattern used for the telemetry data will appear in words 0 through 2 of each PCD minor frame.

i. Minor-Frame Identification (MFID)--A 0 to 127 count of minor frames will appear in word 65 of each PCD minor frame (see Figure 17).

j. Major Telemetry Frame Identification--Word 72 of minor frames 96 through 103 of the second, third, and fourth PCD major frames of a four-frame set (Figure 15) will contain a unique identifier (1, 2, or 3).

k. TM Housekeeping Telemetry--A total of 248 bits of TM housekeeping telemetry data may be stripped out of the telemetry format by the OBC and sent to the formatter. The data will appear in word 72 of minor frames 16 through 46 of the third PCD major frame after the telemetry major-frame pulse. (See Figure 15.) This major frame will carry the identifier "2" in place of time code. Specific TM telemetry data items are given in Table 9a-1.

Table 9
Time Code Format in Payload Correction Data
(word 72 of minor frames 96 through 102
of the first PCD major frame in a cycle)

Minor-Frame Number	Time Code Word Number	Words 72 Bits 0-7	Content of Word 72
96	1	0-3 4-7	Spacecraft ID Hundreds of days
97	2	0-3 4-7	Tens of days Units of days
98	3	0-3 4-7	Tens of hours Units of hours
99	4	0-3 4-7	Tens of minutes Units of minutes
100	5	0-3 4-7	Tens of seconds Units of seconds
101	6	0-3 4-7	Hundreds of milliseconds Tens of milliseconds
102	7	0-3 4-7	Units of milliseconds Fractions of milliseconds (LSB = 1/16 millisecond)
103	-	0-7	NASA use

Notes: Bits 0-7 = Two BCD words in format (MSB-LSB), (MSB-LSB). Spacecraft ID are encoded as follows:
1110 = Landsat-4
1101 = Landsat-5

Table 9a-1
TM Housekeeping Telemetry

Word 72 of Minor Frame Number	Description	Bit	Standard Mode
16	Blackbody temperature, °C		
17	Silicon focal-plane assembly (FPA), °C		
18	Calibration shutter flag temperature, °C		
19	NASA use		
20	Baffle temperature, °C		
21	Cold FPA monitor temperature, °C		
22	NASA use		
23	NASA use		
24	Scan-line corrector temperature, °C		
25	Calibration shutter hub temperature, °C		
26	NASA use		
27	NASA use		
28	Relay optics temperature, °C		
29	NASA use		
30	NASA use		
31	NASA use		
32	Serial Word B:		
	Band 1 On/Off	0	1
	Band 2 On/Off	1	1
	Band 3 On/Off	2	1
	Band 4 On/Off	3	1
	Band 5 On/Off	4	1
	Band 6 On/Off	5	1
	Band 7 On/Off	6	1
	Cold Stage Telemetry On/Off (see Note 5)	7	1
33	NASA use		
34	Serial Word D:		
	Cal Lamp 1 On/Off	0	1
	Cal Lamp 2 On/Off	1	1
	Cal Lamp 3 On/Off	2	1
	Cal Lamp 1 Override On/Off (see Note 6)	3	0
	Cal Lamp 2 Override On/Off (see Note 6)	4	0
	Cal Lamp 3 Override On/Off (see Note 6)	5	0
	Cal Sequencer On/Off	6	1
	Multiplexer Backup On/Off	7	1
35	Serial Word E:		
	NASA use	0	-
	NASA use	1	-

Table 9a-1 (Continued)

Word 72 of Minor Frame Number	Description	Bit	Standard Mode
	Blackbody On/Off (see Note 7)		
	Blackbody T2 On/Off (see Note 7)		
	Blackbody T3 On/Off (see Note 7)		
	Blackbody Backup On/Off	5	0
	SME 1 On/Off (see Note 1)	6	1
	SME 2 On/Off (see Note 1)	7	0
36	Serial Word F:		
	NASA use	0	-
	NASA use	1	-
	NASA use	2	-
	NASA use	3	-
	NASA use	4	-
	NASA use	5	-
	Multiplexer On/Off	6	1
	Midscan Pulse On/Off (Primary) (see Note 4)	7	0
37	Serial Word G:		
	Scan Line Corrector 1 On/Off	0	1
	Scan Line Corrector 2 On/Off	1	0
	Cal Shutter On/Off	2	1
	Cal Shutter Phase Lock Y/N (see Note 2)	3	1
	Cal Shutter Amplitude Lock Y/N (see Note 2)	4	1
	Backup Shutter On/Off	5	0
	Backup Shutter Phase Lock Y/N	6	0
	Backup Shutter Amplitude Lock Y/N	7	0
38	NASA use		
39	Serial Word L:		
	DC Restore Normal/Not Normal	0	1
	Frame DC Restore Selected Y/N	1	0
	Telemetry Scaling On/Off (see Note 3)	2	1
	NASA use	3	-
	NASA use	4	-
	Midscan Pulse Backup On/Off (see Note 4)	5	0
	SME 1 Select SAM (see Note 1)	6	1
	NASA use	7	-
40	Primary mirror temperature, °C		
41	NASA use		
42	Secondary mirror temperature, °C		
43	NASA use		
44	NASA use		
45	NASA use		
46	NASA use		

Table 9a-1 (Continued)

Notes concerning serial words:

[1]If scan mirror electronics 2 (SME-2) is selected, then
Serial Word E--Bit 6 = 0
Serial Word E--Bit 7 = 1
Serial Word L--Bit 6 = 0

[2]CAL shutter amplitude lock (Serial Word G--Bit 4 = 1) indicates that the shutter is moving with the correct amplitude.

CAL shutter phase lock (Serial Word G--Bit 3 = 1) indicates that the phasing between the shutter and scan mirror is correct.

Both phase and amplitude lock must be present or shutter may interfere with the image data.

[3]If telemetry scaling (Serial Word L--Bit 2 = 0) is off, then blackbody, baffle and silicon focal plane temperatures are invalid.

[4]If midscan pulse (Serial Word F--Bit 7 = 1) or midscan pulse backup (Serial Word L--Bit 5 = 1) are on, midscan code will be injected into the image data at midscan.

[5]Cold stage telemetry off (Serial Word B--Bit 7 = 0) implies that cold stage FPA temperature data is not valid.

[6]Calibration lamp override on (Serial Word D--Bits 3,4, or 5 = 1) implies that the indicated lamp current active control loop is not in use, and that lamp radiance may have changed.

[7]Blackbody, Blackbody T2, and Blackbody T3 On/Off (Serial Word E--Bits 2-4) combine to indicate <u>commanded</u> blackbody state as follows:

Blackbody State	Bit 2	Bit 3	Bit 4
Off commanded	0	0	0
T1 commanded	1	0	0
T2 commanded	1	1	0
T3 commanded	1	0	1

The TM housekeeping telemetry in the PCD cycle was sampled at the PCD time code for the cycle minus 16.316 seconds.

Each telemetry function can be converted from counts (C's) which range from 0 to 255 to engineering units (EU's) by using the following equation:

$$EU = A_0 + A_1C + A_2C^2 + A_3C^3 + A_4C^4 + A_5C^5$$

The units and coefficients for each telemetry point are defined in Table 9a-2. The information in Table 9a-2 applies to both Landsat-4 and Landsat-5.

l. Spare Telemetry--Up to 176 bits of telemetry data may be stripped out and output in telemetry in the same manner as the TM housekeeping data.

   The data will appear in word 72 of minor frames 28 through 49 of the first PCD major frame after the telemetry major-frame pulse. (See Figure 15.) This major frame carries the spacecraft time code.

   The data in the PCD cycle was sampled at the PCD time code for the cycle minus 16.316 seconds.

   At present, four 8-bit words have been defined as shown in Table 9b.

m. Frame Error--A "Frame Error Bit" is transmitted as the MSB of word 72 of minor frame 116 of each PCD major frame (see Figure 16). A digital zero indicates that the expected telemetry major frame pulse either did not occur or did not line up with the start of the first PCD major frame. Under this condition, all other data in the associated PCD major frame may be invalid.

n. A/D Ground Reference--The output of the Angular Displacement Sensor Assembly (ADSA) A/D Converter for a grounded input is transmitted in word 72 of minor frames 116 and 117 of each PCD major frame (Figure 16).

5.4.8 High-Resolution Data

The high-resolution sensor data usually follows the PCD word and completes the minor frame. The format is always 96 8-bit words unless preempted by the next SLS. During the first six minor frames following the SLS, these data slots are taken up with time code information. All time, picture, and calibration data words are PN-encoded.

5.4.9 TM Time Code

The TM time code information contained in the first six minor frames after scan-line start represents the time of the scan-line start. Time code minor frames contain 102 8-bit words. The first four words are dedicated to minor-frame sync. The minor-frame sync word is:

```
MSB (output first)
0000  0010  0011  0111  0001  0110  1101  0001
                                          LSB
```

Table 9a-2
TM Housekeeping Telemetry Conversion Coefficients

Telemetry Function	Engineering Units	CONVERSION COEFFICIENTS:					
		A_0	A_1	A_2	A_3	A_4	A_5
Blackbody Temperature	degrees C	17.073	0.10263	2.2576×10^{-4}	0.0	0.0	0.0
Silicon FPA Temperature	degrees C	10.049	0.83456×10^{-1}	0.14176×10^{-3}	0.0	0.0	0.0
Calibration Shutter Flag Temperature	degrees C	36.898	-0.1598	1.957×10^{-6}	0.0	0.0	0.0
Baffle Temperature	degrees C	-2.9072	0.089583	2.7115×10^{-4}	0.0	0.0	0.0
Cold Stage FPA Temperature	degrees C	-162.94	-0.1000	0.0	0.0	0.0	0.0
Scan-Line Corrector	degrees C	147.84	-1.8384	0.016092	-9.2715×10^{-5}	2.839×10^{-7}	-3.683×10^{-10}
Calibration Shutter Hub Temperature	degrees C	121.23	-1.9147	0.019275	-0.11865×10^{-3}	0.37343×10^{-6}	-0.47899×10^{-9}
Relay Optics Temperature	degrees C	121.23	-1.9147	0.019275	-0.11865×10^{-3}	0.37343×10^{-6}	-0.47899×10^{-9}
Primary Mirror Temperature	degrees C	121.23	-1.9147	0.019275	-0.11865×10^{-3}	0.37343×10^{-6}	-0.47899×10^{-9}
Secondary Mirror Temperature	degrees C	121.23	-1.9147	0.019275	-0.11865×10^{-3}	0.37343×10^{-6}	-0.47899×10^{-9}

Table 9b
Spare Telemetry in PCD Subcom (Word 72)

Minor Frame	Function		
28	Ephemeris Source Identification	$(00)_{16}$ = GPS $(01)_{16}$ = Uplink	
29	Roll Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below
30	Pitch Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	
31	Yaw Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	

IRU Channel

	Gyro 1	Gyro 2
Roll	B	A
Pitch	B	C
Yaw	A	C

Time is binary-coded decimal (BCD) days and Greenwich mean time (GMT) hours, minutes, seconds, milliseconds, and 1/16 millisecond. A 4-bit spacecraft identifier is included within the time code. Table 8 shows the output format of the first six minor frames of each major frame (i.e., set of 16 scan lines).

5.4.10 Midscan Code Format

If enabled by command, a midscan code will replace portions of the data in the last 96 words of a scene data minor frame. The midscan code consists of 48 words of white (level 255) data followed by 48 words of black (level 0) data. The midscan code will start within two to nine words of the second scan-angle monitor pulse following scan-line start, which will occur approximately in minor frame 3160. The midscan code can interrupt scene data at word boundaries and need not be coherent with a minor frame. In most cases, the midscan code will occupy portions of two minor frames. The midscan code does not replace minor-frame sync, Band 6, and PCD words. Midscan code data are PN-encoded, have the four LSB's inverted, and are output MSB first. NASA intends to use this mode infrequently on a noninterference basis with foreign acquisition requirements. Upon special request, foreign ground stations could receive MSS or TM imagery with midscan code enabled. For TM, this is unnecessary because first half scan time error and second half scan time error is included in the line length code described in Section 5.4.13. This line length code is part of the X-band data.

5.4.11 End of Scan

When the end-of-scan pulse occurs, approximately 6320 minor frames into the major frame, the TM will generate 48 words of dark (level 0), followed by 48 words of bright (level 255), 48 words of dark, and 48 words of bright in sequence. These words will replace the high-resolution data in the current minor frames but not the minor-frame sync, Band 6 sensor, or PCD. Insertion of this end-of-scan code will allow determination of end of scan by ground processing systems. The first bit of end-scan code occurs within two to nine word times of the TM mirror scan-angle monitor pulse. The end-scan code is not coherent with the minor frame, but does start on an 8-bit word boundary. (Accordingly, line length is a nonintegral number of minor frames, but is an integral number of 8-bit words.) The 192 words of end-scan code will usually occupy portions of three minor frames. End-scan code data are PN-encoded, four LSB's inverted, and output MSB first. The image data appearing after the end scan code results from continuing motion of the scan mirror.

5.4.12 Line-Length Data

After the end scan code has finished, the next two minor frames contain a line-length code that indicates the time from line start to midscan, the time from midscan to line stop, and scan direction. The line-length data appearing in a scan is for the previous scan.

The scan mirror assembly transmits a 32-bit serial data word to the multiplexer at the end of each scan (Figure 8). In the scan angle monitor mode, the data are as shown in Figure 20. As indicated, each bit of the 32-bit line-length code is repeated 47 times and encoded in six consecutive 8-bit bytes (48 bits total).

The units of magnitude are clock pulses where the clock rate is 1/16 the TM 84.903 bit rate. Minus magnitudes are given in 2's complement notation.

SHSERR = time error in clock counts from the nominal midscan to line stop count of 161,165

FHSERR = time error in clock counts from the nominal line start to midscan count of 161,164

For example, a typical engineering model sample is:

000000100100	111111011101	00000000
Decimal = 36	Decimal = -35	Reverse

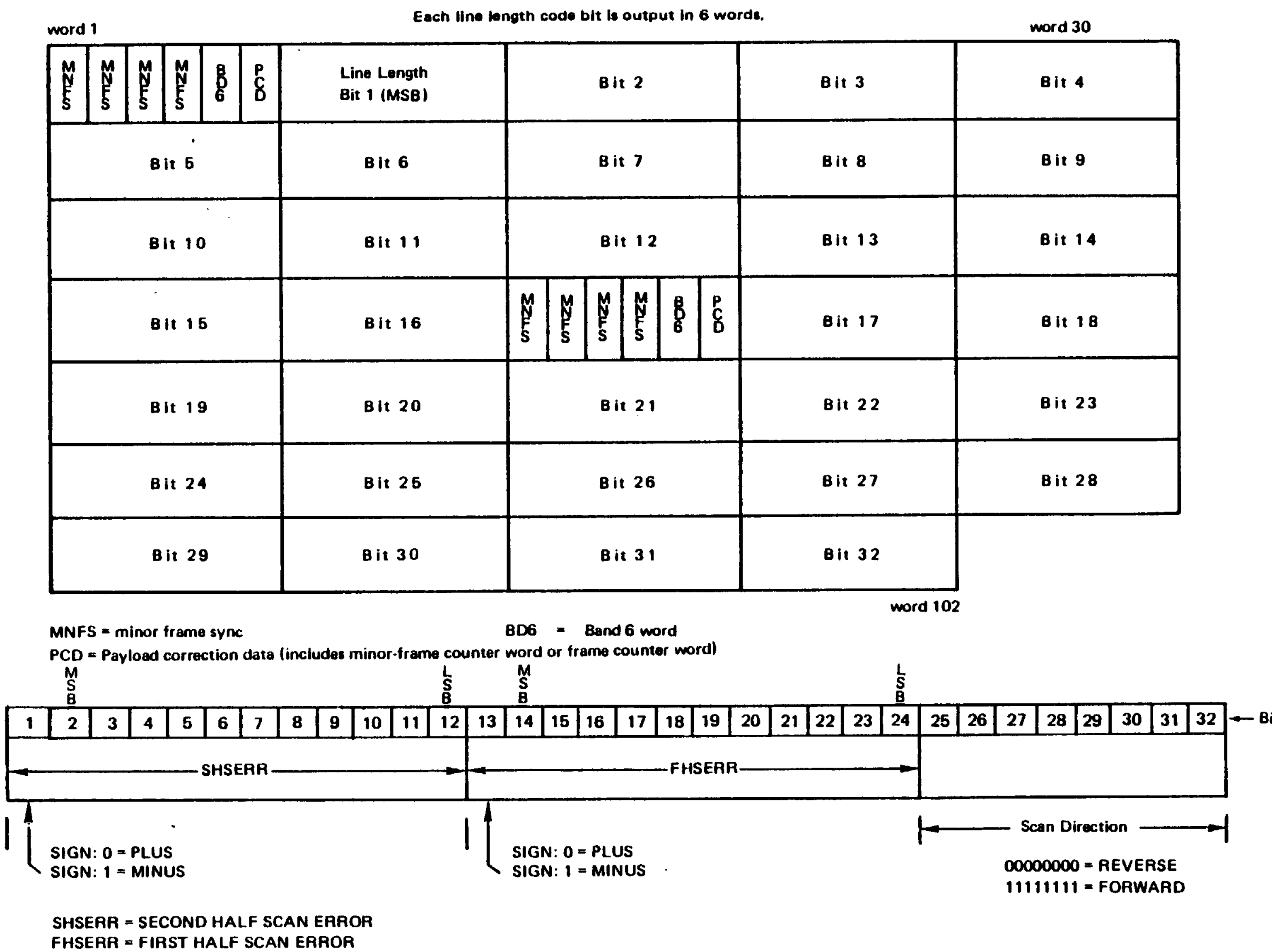


Figure 20. Line-Length Format

SHSERR = (36) (1/(84.903/16)) = 6.78 microseconds
FHSERR = (-35) (1/(84.903/16)) = -6.60 microseconds

Active scan time = ((161,165 + 161,164) - (SHSERR + FHSERR))
x (1/(84.903/16)) = 60,743 microseconds

Typical magnitudes of FHSERR and SHSERR for the Landsat-4 instrument are +65 and -65 counts on forward scans and -135 and +135 counts on reverse scans. Typical magnitudes of FHSERR and SHSERR for the Landsat-5 instrument are -190 and +190 counts on forward scans, and +155 and -155 counts on reverse scans. The image data appearing after the line length/scan direction information results from the continuing motion of the scan mirror, and continues until shutter obscuration occurs.

5.4.13 DC Restore and Calibration Data

After transmission of the line length and the scan direction data, high resolution sensor data will resume until the sinusoidally oscillating shutter obscures the optical path to the detectors. During this period, the internal calibration and dc restoration data are transmitted as described in Paragraph 5.3. Table 7 provides approximate start- and end-time periods when calibration and dc restoration occur for both the forward and reverse scans. Refer to Table 7 for minor-frame shutter obscuration timing.

5.4.14 Postamble Data

Postamble data commence at the 960th minor frame following end-scan code. Postamble will continue for approximately 1 millisecond, until it is interrupted by major-frame sync. Major-frame sync will interrupt only at word boundaries. Postamble minor frames contain the standard minor-frame sync (4), Band 6 data, and PCD words. The remaining words of each minor frame shall contain the inverse of the PN-code shown in Figure 9. The inverse PN-code data are not encoded. The PN data start with the 49th bit of the pattern and are reset at each minor frame. (Refer to Table 6 for a list of timing and minor-frame word counts for postamble.)

5.5 TM DATA PROCESSING CONSTANTS

The values of certain spacecraft and sensor constants required in ground processing are provided in Appendix C.

6. TELEMETRY FORMAT

For Landsat-4/-5, there will be two fixed telemetry formats, one engineering format, and one mission format. Both formats can operate at 1 kbps or 8 kbps. The mission format will be transmitted to ground stations at 8 kbps. A minor telemetry frame consists of 1024 bits that represent 128 8-bit words. Sixteen of the 128 words are in a fixed position and are located symmetrically in the format as four groups of four words each. A major frame consists of 128 minor frames.

6.1 REAL-TIME TELEMETRY AND HIGH-RATE DATA FORMATS FOR GSTDN BACKUP STATIONS AND FOREIGN GROUND STATIONS

Real-time spacecraft telemetry (i.e., housekeeping and OBC data reports), high-rate data (PCD, OBC memory dump, or recorded telemetry data), and FS ranging signals are downlinked by the S-band transponder. The PCD, OBC memory dump, recorded telemetry data, and ranging signals are present when being transmitted to a GSTDN back-up station. These data are not intended for acquisition and use by foreign ground stations.

6.2 BIT RATE

The output bit rates for direct telemetry data transmission to GSTDN and foreign ground stations are shown in Table 10.

6.3 MODULATION TECHNIQUE

The real-time spacecraft telemetry is biphase-S phase-shift keyed on a 1.024-MHz subcarrier which phase-modulates the carrier (Biphase-S/PSK/PM) and is radiated through the omni antenna. Twenty percent of the power is in the residual carrier. The biphase-S and NRZ data formats are described and shown in Table 11.

6.4 WORD LENGTH

The word length is 8 bits assembled into analog, passive analog, bilevel (discrete), or serial digital.

6.5 FORMATS

Three formats are supported by Landsat-4/-5: Format I (engineering), Format II (mission), and Format III (OBC dump). The mission format is to be used by GSTDN and foreign stations during normal on-orbit payload activity. The engineering format is to be used by NASA when the spacecraft is deployed in an orbit-adjust or safe-hold activity, and the OBC dump is to be used by NASA to maintain and verify OBC software.

7. MISSION FORMAT TELEMETRY

This section describes the Landsat-4/-5 Mission telemetry data to be provided to the foreign ground stations.

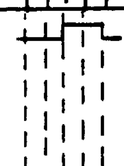
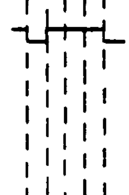
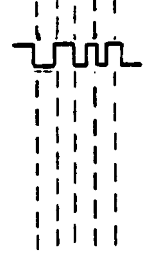
7.1 TELEMETRY FRAME FORMAT

Table 12 presents the minor-frame word (column) allocations for the mission format. Each minor-frame word is sampled every 128 milliseconds at 8 kbps. Ten mirror-frame words (i.e., columns

Table 10
Telemetry Bit Rates

Telemetry Type	Bit Rate (kbps)	Receiving Site
Real-time spacecraft telemetry	8	GSTDN or foreign stations
Payload correction data	32	GSTDN or foreign stations

Table 11
Data Bit Stream Formats

Data Format	...11001...	Description
NRZ-L		NRZ level (or NRZ change): "ONE" is represented by one level. "ZERO" is represented by the other level.
NRZ-M		NRZ-mark (differential encoding): "ONE" is represented by a change in level. "ZERO" is represented by no change in level.
BIϕ-S		Biphase, a transition occurs at the beginning of every time (T) period. "ZERO" is represented by a second transition one-half time period later. "ONE" is represented by no second transition.

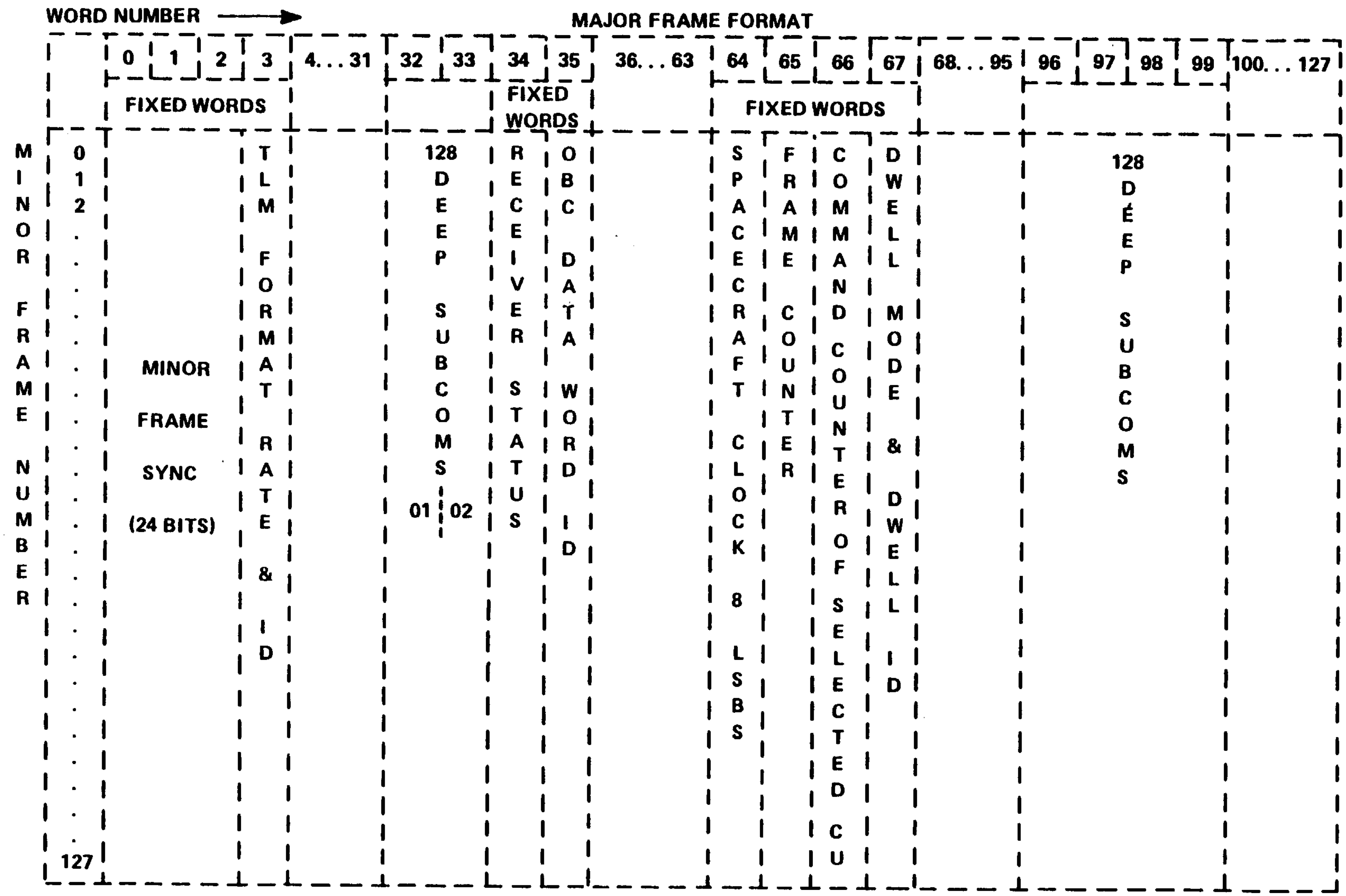
0, 1, 2, 3, 34, 35, 64, 65, 66, and 67) are reserved for specific spacecraft data and are designated as fixed words. Six words (i.e., 32, 33, 96, 97, 98, and 99) have been allocated for subcommutated data so that data are sampled at least once every major frame. Twenty-five additional words in each minor frame (i.e., columns 91 to 95 and 108 to 127) have been reserved for OBC reports.

7.2 TELEMETRY FORMAT

7.2.1 Major Frame

The major-frame telemetry format is a 128- by 128-column matrix. A minor frame (row) contains 128 8-bit words (columns) and is

Table 12
Mission Format Telemetry Matrix Construction



shown in Table 12. A major frame consists of 128 minor frames. The format starts in row 0, column 0 and proceeds sequentially through the matrix until the final word in row 127, column 127 is transmitted, thus completing a major frame. The MSB is transmitted first in a minor-frame word. The major-frame duration is 16.384 seconds at 8 kbps.

7.2.2 Minor Frame

Each minor frame contains 128 words. The first three words are used for the minor-frame synchronization. The minor-frame counter is located in word location 65. These data words are located in fixed word locations as shown in Table 12. At the 8-kbps rate, a word period is 1 millisecond.

7.2.3 Telemetry Control Words

7.2.3.1 Synchronization--The first three words in each minor frame are used for minor-frame synchronization. These 24 sync bits are described as follows:

WORD 0 MSB	WORD 1	WORD 2 LSB
11111010	11110011	00100000

Since the telemetry bit stream is transmitted MSB first, this sync pattern is received as shown. In hexadecimal, the sync pattern is $FAF320_{16}$.

7.2.3.2 Frame Counter--Word 65 of the minor frame is the frame counter. At the end of each minor frame, the counter is incremented by one, and the new value (n+1) is placed in word 65 in the subsequent minor-frame counter location. This process is continued until a maximum count of 255 is reached and the process is repeated. Only the seven LSB's are needed to determine the frame-counter contents for subcom word ID (0 to 127). The bit pattern sequence is shown in Figure 17.

7.2.3.3 Other Control Words--There are two other control words in each telemetry minor frame that may be required in ground processing. The contents of these words are described below and in the following paragraphs:

a. Word 3

(1) Bit rate (bits 0, 1, and 2):

000 = 1 kbps (engineering use only)
011 = 8 kbps (normal use)

(2) Format ID (bits 3 and 4):

01 = format I (engineering), for NASA use only
10 = format II (mission)
11 = OBC controlled, for NASA use only

(3) Real-time computer data dump (bit 6)

0 = OBC dump, for NASA use only
1 = real-time spacecraft/normal payload operation

b. Word 35 - Computer Data Word ID (8 bits)--Identifies the OBC report number contained in this minor frame. The 25-word OBC contribution to telemetry minor-frame word locations 91 to 95 and 108 to 127 can be identified by this means.

7.2.3.4 Subcommutation Mission Format--There are a total of 31 subcommutated words in a minor frame: 6 normal and 25 OBC words. The length of the subcommutation cycle is one full major frame. The 7-bit (0 to 127) minor-frame counter contained in word 65 is used to identify subcom words 32, 33, and 96 through 99. Words may be sampled in these columns one or more times per major frame. For example, a telemetry word assigned a sample rate of once per major frame will be sampled approximately once every 16 seconds at 8 kbps. Those words that require sampling faster than once per major frame have been equally spaced in subcom columns. As an example, a word requiring four samples per major frame is sampled first in minor frames N, second in minor-frame N+32, third in N+64, and fourth in N+96. The OBC reports contained in words 91 to 95 and 108 to 127 are subcommutated as a group, and are indexed to the OBC report number contained in word 35.

7.2.3.5 Nonfixed Columns--There are 112 other columns in the mission format for the assignment of subsystem telemetry data.

7.2.4 Telemetry Assignments by User

Tables 13 through 19 list the telemetry data of interest to Landsat-4/-5 ground station operators. Table 13 gives a telemetry function description and location in the telemetry matrix for data sampled in each minor frame, and Tables 14 through 19 cover the six subcommutators. See Section 8 for a description of the contents of OBC reports.

8. ONBOARD COMPUTER REPORTS

The OBC contributes 128 reports to each telemetry major frame and 1 report to each telemetry minor frame. The length of the reports are mission unique, but must be at least two words long. The first word is output in column 35 and gives the report number; the remaining word or words give the data being reported. The

Table 13
Mission Telemetry Frame Format

Minor Frame Word	Description	Minor Frame Word	Description	Minor Frame Word	Description
00	Minor frame sync word 00	43		85	
01	Minor frame sync word 01	44	Calib. lamp 1 current (ma=0.671969 x counts)	86	
02	Minor frame sync word 02	45	Calib. lamp 2 current } (ma=0.710553 x counts)	87	
03	Telemetry rate, format, ID	46	Calib. lamp 3 current }	88	
04		47*	Blackbody temperature	89	
05		48*	Silicon focal plane assembly (FPA) temperature	90	
06		49*	Calibration shutter flag temperature	91	OBC data word 1
07		50*	Backup shutter temperature	92	OBC data word 2
08		51*	Cold stage FPA temperature	93	OBC data word 3
09		52*	SLC temperature	94	OBC data word 4
10		53*	Baffle temperature	95	OBC data word 5
11		54		96	Subcommutation 03
12		55		97	Subcommutation 04
13		56		98	Subcommutation 05
14		57		99	Subcommutat.on 06
15		58		100	
16		59		101	
17		60		102	
18		61		103	
19		62		104	
20		63		105	
21		64		106	
22		65	Minor-frame counter	107	
23		66		108	OBC data word 6
24		67		109	OBC data word 7
25		68		110	OBC data word 8
26		69		111	OBC data word 9
27		70		112	OBC data word 10
28		71		113	OBC data word 11
29		72		114	OBC data word 12
30		73		115	OBC data word 13
31		74		116	OBC data word 14
32	Subcom 01	75		117	OBC data word 15
33	Subcom 02	76		118	OBC data word 16
34		77		119	OBC data word 17
35	OBC data identifier	78		120	OBC data word 18
36		79		121	OBC data word 19
37		80		122	OBC data word 20
38		81		123	OBC data word 21
39		82		124	OBC data word 22
40		83		125	OBC data word 23
41		84		126	OBC data word 24
42				127	OBC data word 25

*See 5.4.7.2k for method of conversion to engineering units. Values in minor frame N are sampled at major frame time (see Table 14) minus 16.384 seconds plus 0.0128 x N.

Table 14
Subcommutator 01--Minor Frame Word 32

Minor Frame	Description	
00	Time-code word 1	Ref. Table 9 for interpretation of time code words
01	Time-code word 2	
02	Time-code word 3	
03	Time-code word 4	
04	Time-code word 5	
05	Time-code word 6	
06	Time-code word 7	
07	NASA use	
08		
09		
10		
11		
12	Calibration lamp 1 current	
13		
14		
15		
16		
17	All calibration lamps on	
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31	Calibration lamp 2 current	
32		

Minor Frame	Description
33	
⋮	
50	Calibration lamp 3 current
⋮	
74*	Blackbody temperature
75*	Silicon focal-plane assembly temperature
⋮	
78*	Calibration shutter flag temperature
79*	Calibration shutter hub temperature
⋮	
87*	Baffle temperature
⋮	
89*	Cold focal-plane assembly monitor temperature
⋮	
92*	Relay optics temperature
⋮	
98*	Primary mirror temperature
⋮	
100*	Secondary mirror temperature
⋮	
112*	Scan-line corrector temperature
⋮	
128	

*See 5.4.7.2k for method of conversion to engineering units. Values are sampled at major frame time (time code words 1-7) minus 16.316 seconds.

Table 15
Subcommutator 02--Minor Frame Word 33

Minor Frame	Description	Minor Frame	Description
00		33	
01		34	
02		35	
03		36	
04		37	
05		38	
06		39*	MSS band 1 channel A video (detector 1)
07		40	
08		41	
09		42	
10		43	
11		44	
12		45*	MSS band 2 channel A video (detector 7)
13		46	
14		47	
15		48	
16		49	
17		50	
18		51*	MSS band 3 channel A video (detector 13)
19		52	
20		53	
21		54	
22		55	
23		56	
24		57*	MSS band 4 channel A video (detector 19)
25			
26			
27			
28			
29			
30			
31			
32		128	

*Diagnostic monitor, for use in verifying channel operation.

Table 16
Subcommutator 03--Minor Frame Word 96

Minor Frame	Description	Minor Frame	Description
00*	Bilevel word 706 = MSS system power A ON/OFF (bit 0) MSS system power B ON/OFF (bit 1)	31	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30		128	

*1 = ON/0 = OFF

Table 17
Subcommutator 04--Minor Frame Word 97

Minor Frame	Description	Minor Frame	Description
00*	Bilevel word 801: MSS multiplexer COMPRESSED/LINEAR (Bit 6)	31	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30		128	

*1 = COMPRESSED/0 = LINEAR

Table 18
Subcommutator 05--Minor Frame Word 98

Minor Frame	Description	Minor Frame	Description
00*	Bilevel word 802: MSS band 1 gain HIGH/LOW (bit 0) MSS band 2 gain HIGH/LOW (bit 1) MSS band 1 low voltage ON/OFF (bit 2) MSS band 2 low voltage ON/OFF (bit 3) MSS band 3 low voltage ON/OFF (bit 4) MSS band 4 low voltage ON/OFF (bit 5)	27 → 128	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			

*1 = HIGH or ON/0 = LOW or OFF

Table 19
Subcommutator 06--Minor Frame Word 99

Minor Frame	Description	Minor Frame	Description
00*	Bilevel word 803: MSS high voltage ON/OFF (bit 0) MSS band 1 high voltage A ON/OFF (bit 1) MSS band 1 high voltage B ON/OFF (bit 2) MSS band 2 high voltage A ON/OFF (bit 3) MSS band 2 high voltage B ON/OFF (bit 4) MSS band 3 high voltage A ON/OFF (bit 5) MSS band 3 high voltage B ON/OFF (bit 6)	26	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25		128	

*1 = ON/0 = OFF

Landsat-4/-5 flight software contributions to telemetry are presented in this section. The OBC data items contained in the telemetry stream and their output rates are listed along with the format of the reports as they appear in the telemetry minor frames.

The number of OBC reports generated by the various flight elements, as well as the rate at which the reports are output per major frame, is tabulated in Table 20 and Figures 21 through 28. The "Samples/Major-Frame" (Tables 21 and 22) column contains the total reports contributed by each processor to each major frame. The Landsat-4/-5 flight software will contribute 103 reports to each major frame of telemetry, 17 of which are useful in ground processing of image data. This leaves 25 reports as a reserve for growth in the number of OBC data items contributed to telemetry. Each report will be 25 words long. The rate at which the various reports are output ranges from one to eight times per major frame. The order in which the OBC reports are output is defined in Table 20. The ACS telemetry is given in Table 21 and Figures 21 through 27. The ephemeris computation telemetry report is given in Figure 28 and Table 22. Most of the data in Reports 1, 2, 8, 9, 10, and 11 are intended primarily for operation of the spacecraft and for engineering purposes. Ephemeris and attitude data in the OBC reports are the same as in the PCD subcom except for sampling and scaling. The epoch for the attitude estimates (ACS Telemetry Reports 1 and 2), gyro compensation data (ACS Telemetry Report 10) and ephemeris (Ephemeris Computation Telemetry Report 1) is defined by the parameter T_f in ACS Report No. 11.

The relationship between these reports and T_f is as defined below:

Minor frame containing T_f	Minor frames containing reports for epoch T_f
30	8, 9, 16, 27
62	40, 41, 48
94	72, 73, 80
126	104, 105, 112

Gyro data in ACS Telemetry Report 12 are also related to T_f, as explained below. Gyro data (CNGX, CNGY, CNGZ) used by NASA for MSS processing are provided in ACS Telemetry Report 12. The three samples (three gyro axes) in a set are sampled simultaneously, and each report contains four sets sampled at 0.512-second intervals. The first set within the report that occurs in minor frame 15 corresponds to a time 0.512 second before the time T_f which appears within (ACS Telemetry Report 11) minor frame 30. The data continue uniformly at 0.512-second intervals. These gyro data are uncompensated (alignment, bias, and scale factor errors are not corrected) and may be filtered or unfiltered. (A presampling filter is available and if in use, FLTROFF in ACS Telemetry Report 8 is set to 1. The filter has unity dc gain and a break frequency of approximately 0.5 Hz. This filter is not currently being used;

Table 20
Onboard Computer Telemetry Report Sequence

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
0				
1				
2				
3				
4				
5				
6				
7				
8	1	Attitude control system (ACS) telemetry report	1	See Fig. 21
9	2	ACS telemetry report	2	See Fig. 22
10				
11				
12				
13				
14				
15	12	ACS telemetry report	12	See Fig. 27
16	13	Ephemeris computation telemetry report	1	See Fig. 28
17				
18				
19				
20				
21				
22				
23	8	ACS telemetry report	8	See Fig. 23
24				
25				
26	9	ACS telemetry report	9	See Fig. 24
27	10	ACS telemetry report	10	See Fig. 25
28				
29				
30	11	ACS telemetry report	11	See Fig. 26
31	12	ACS telemetry report	12	
32				
33				

Table 20
Onboard Computer Telemetry Report Sequence (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
34				
35				
36				
37				
38				
39				
40	1	ACS telemetry report	1	
41	2	ACS telemetry report	2	
42				
43				
44				
45				
46				
47	12	ACS telemetry report	12	
48	13	Ephemeris computation telemetry report	1	
49				
50				
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				
61				
62	11	ACS telemetry report	11	
63	12	ACS telemetry report	12	
64				
65				
66				
67				
68				
69				
70				
71				
72	1	ACS telemetry report	1	
73	2	ACS telemetry report	2	
74				
75				

Table 20
Onboard Computer Telemetry Report Sequence (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
76				
77				
78				
79	12	ACS telemetry report	12	
80	13	Ephemeris computation telemetry report	1	
81				
82				
83				
84				
85				
86				
87				
88				
89				
90				
91				
92				
93				
94	11	ACS telemetry report	11	
95	12	ACS telemetry report	12	
96				
97				
98				
99				
100				
101				
102				
103				
104	1	ACS telemetry report	1	
105	2	ACS telemetry report	2	
106				
107				
108				
109				
110				
111	12	ACS telemetry report	12	
112	13	Ephemeris computation telemetry report	1	
113				
114				
115				
116				
117				

Table 20
Onboard Computer Telemetry Report Sequence (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
118				
119				
120				
121				
122				
123				
124				
125				
126	11	ACS telemetry report	11	
127	12	ACS telemetry report	12	

if plans to use it develop, additional information will be provided.) To compensate the gyro data:

a. Obtain, negate, and scale CNGX, CNGY, and CNGZ to radians

b. Rotate these to the ACS reference axes

c. Subtract θ_{BX}, θ_{BY}, and θ_{BZ}

d. Perform frequency response compensation (i.e., apply a digital filter which corrects the phase and amplitude of gyro data--Ref. DRIRU transfer function described in Appendix C) to a 0.4 Hz bandwidth.

Normal spacecraft configuration for imaging is Earth pointing with inertial reference and the gyros in the low-rate mode. Parameters defining this configuration are defined in Table 21 and should be verified from telemetry to assure normal image acquisition.

9. LANDSAT COMMUNICATIONS

The following descriptions summarize the Landsat-4/-5 to foreign ground station communications interface. Additional descriptive material and data are provided in Appendix H.

9.1 LANDSAT X-BAND CHARACTERISTICS

The following information describes the Landsat X-band link characteristics:

a. Frequency: 8.2125 GHz

b. Transmitter power: 44 watts

TLM Word	1	2	3	4	5
OBC Data	θ_x MSB	LSB	θ_Y MSB	LSB	θ_z MSB

6	7	8	9	10
θ_z LSB				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

Output four times per major frame in minor frames 8, 40, 72, and 104.
Sixteen MSB's of double precision θx, θy, θz are downlinked.

Figure 21. ACS Telemetry Report 1

TLM Word	1	2	3	4	5
OBC Data				Wx	Wy

6	7	8	9	10
Wz	Ex		Ey	

11	12	13	14	15
Ez		EPA1		

16	17	18	19	20
EPA2			EPA3	

21	22	23	24	25
EPA3	EPA4			

Output four times per major frame in minor frames 9, 41, 73, and 105.
Eight MSB's of single precision Wx, Wy, Wz are downlinked.
Sixteen MSB's of double precision Ex, Ey, Ez, are downlinked.

Figure 22. ACS Telemetry Report 2

TLM WORD	1	2	3	4	5
OBC DATA	MODE				

6	7	8	9	10
		FLTROFF		

11	12	13	14	15

16	17	18	19	20
		ICAL		

21	22	23	24	25

Figure 23. ACS Telemetry Report 8

TLM WORD	1	2	3	4	5
OBC DATA					

	6	7	8	9	10

	11	12	13	14	15
				SENSTA	

	16	17	18	19	20

	21	22	23	24	25

Figure 24. ACS Telemetry Report 9

TLM Word	1	2	3	4	5
OBC Data	θ_{bx} MSB	LSB	θ_{by} MSB	LSB	θ_{bz} MSB

6	7	8	9	10
θ_{bz} LSB				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

Output once per major frame in minor frame 27.
Sixteen MSB's of double precision θ_{bx}, θ_{by}, θ_{bz} are downlinked.

Figure 25. ACS Telemetry Report 10

TLM Word	1	2	3	4	5
OBC Data	MSB ← T_f →				

6		7	8	9	10
LSB	XXXXX				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

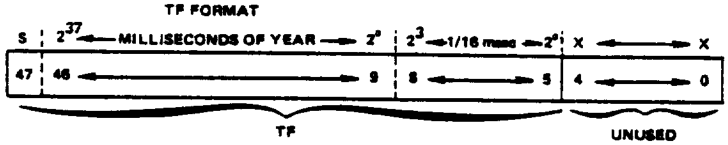
Output four times per major frame in minor frames 30, 62, 94, and 126.

Notes

1) Each value of the T_f in OBC Report ACS 11 defines an epoch at which gyro data is sampled, ephemeris data is computed, and attitude is computed.

Scale = 38, Length = 42 bits preceded by sign bit, and LSB = 1/16 millisecond

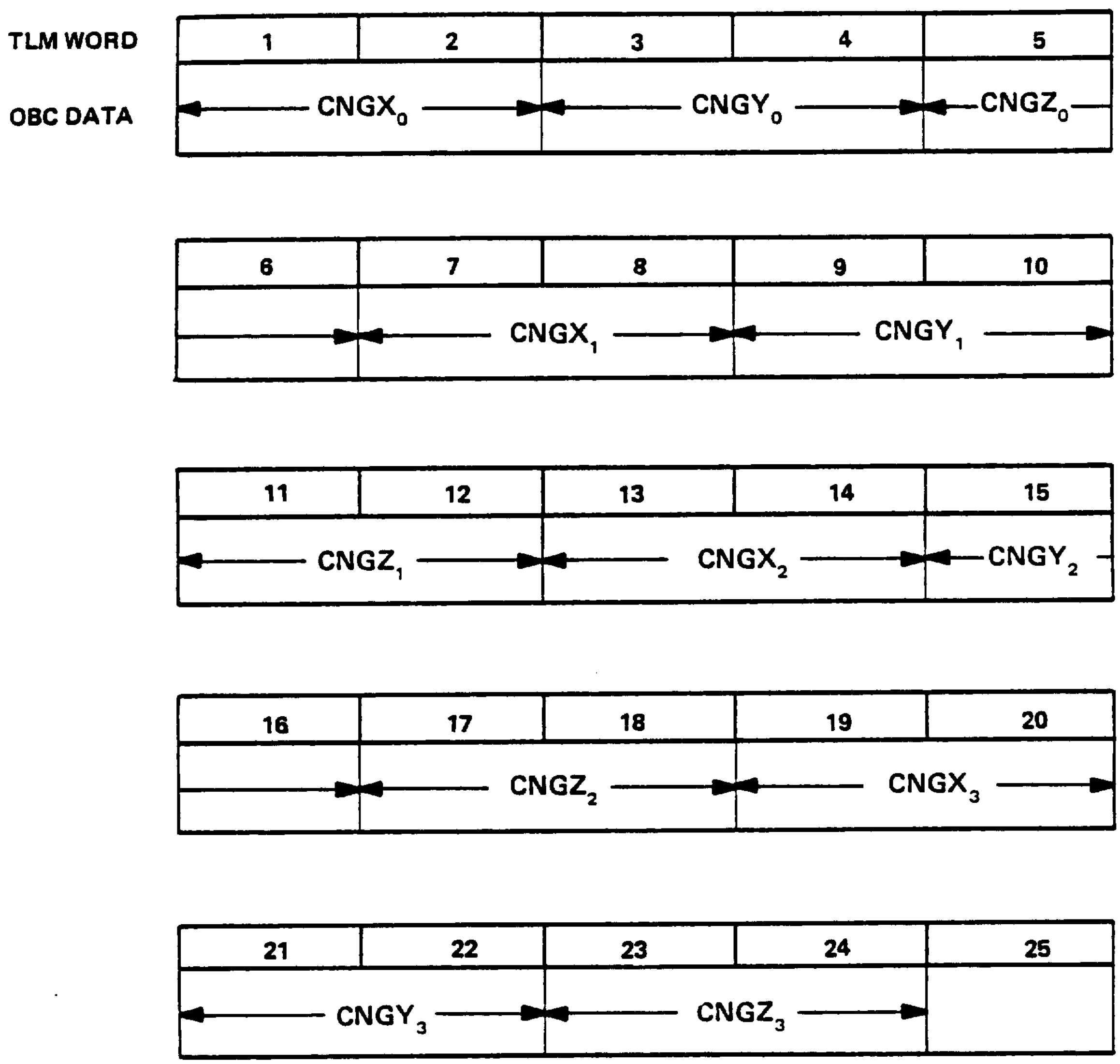
TF FORMAT



The four ACS 11 reports in each major frame correspond to the four Ephemeris report sets and the other ACS reports sampled four times per major frame.

2) T_f is the GMT milliseconds into the year as derived from the DPU clock, referenced to a value of 8.64×10^7 msec at 0000 hours GMT on January 1.

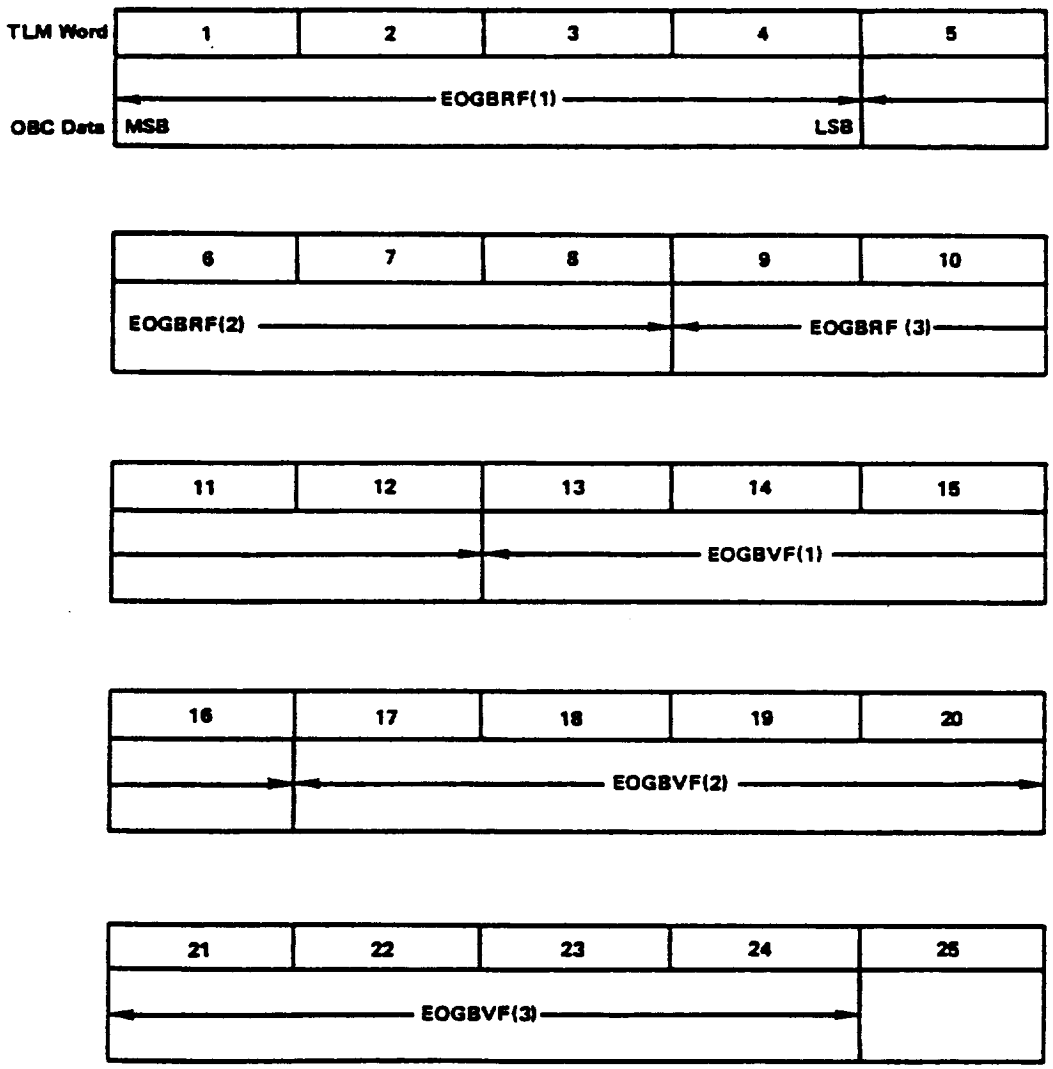
Figure 26. ACS Telemetry Report 11



FOUR SETS OF GYRO DATA PROVIDED:

(1) $CNGX_0$, $CNGY_0$, $CNGZ_0$
(2) $CNGX_1$, $CNGY_1$, $CNGZ_1$
(3) $CNGX_2$, $CNGY_2$, $CNGZ_2$
(4) $CNGX_3$, $CNGY_3$, $CNGZ_3$

Figure 27. ACS Telemetry Report 12



Output four times per major frame in minor frames 16, 48, 80, and 112.

Figure 28. Ephemeris Computation Telemetry Report 1

Table 21
ACS Telemetry

Symbol	Definition	OBC Report	Samples/ Major Frame	Number of Bytes	Range	Unit	LSB Weight
θ_X	Roll axis angular increment each (512 ms) OBC cycle	1	4	2	±0.0312	rad	$1/2^{20}$
θ_Y	Pitch axis angular increment each (512 ms) OBC cycle	1	4	2	±0.0312	rad	$1/2^{20}$
θ_Z	Yaw axis angular increment each (512 ms) OBC cycle	1	4	2	±0.0312	rad	$1/2^{20}$
W_X	Roll axis angular rate	2	4	1	±0.0310	rad/sec	$1/2^{12}$
W_Y	Pitch axis angular rate	2	4	1	±0.0310	rad/sec	$1/2^{12}$
W_Z	Yaw axis angular rate	2	4	1	±0.0310	rad/sec	$1/2^{12}$
E_X	Roll attitude error	2	4	2	±3.9999	rad	$1/2^{13}$
E_Y	Pitch attitude error	2	4	2	±3.9999	rad	$1/2^{13}$
E_Z	Yaw attitude error	2	4	2	±3.9999	rad	$1/2^{13}$
EPA 1		2	4	3	±2	ND	$1/2^{22}$
EPA 2	Euler parameters that specify vehicle orientation relative to Earth-centered inertial frame	2	4	3	±2	ND	$1/2^{22}$
EPA 3		2	4	3	±2	ND	$1/2^{22}$
EPA 4		2	4	3	±2	ND	$1/2^{22}$
θ_{BX}	Roll gyro bias compensation (angle) each (512 ms) OBC cycle	10	1	2	±1.526 E-5	rad	$1/2^{31}$
θ_{BY}	Pitch gyro bias compensation (angle) each (512 ms) OBC cycle	10	1	2	±1.526 E-5	rad	$1/2^{31}$
θ_{BZ}	Yaw gyro bias compensation (angle) each (512 ms) OBC cycle	10	1	2	±1.526 E-5	rad	$1/2^{31}$
TF	Flight software time	11	4	6	2.748E11	msec	1/16
MODE	ACS mode. Earth pointing = 4	8	1	1	4	N/A	1
ICAL	ACS Reference. Earth sensor = 2, Inertial reference = 3	8	1	1	3	N/A	1
SENSTA	Gyro rate mode. Low = 1, High = 0 (Bits 8,7,6)	9	1	1	1	N/A	1
CNGX	X-axis uncompensated gyro data	12	32	2	±1.683 E4	Counts	1/2*
CNGY	Y-axis uncompensated gyro data	12	32	2	±1.683 E4	Counts	1/2*
CNGZ	Z-axis uncompensated gyro data	12	32	2	±1.683 E4	Counts	1/2*
FLTROFF	CNGX, CNGY, CNGZ filter ON = 1, OFF = 0	8	1	1	1	N/A	1

*Low rate mode: 1 count = 1/20 arc second ND = NONDIMENSIONAL

NOTES:

1) $\theta_{X,Y,Z}$ *(angular increment)* – measured angular motion about the ACS reference axes during a 0.512-second period; positive value = positive motion per right-hand rule; data in two's complement form; computed every 0.512 seconds, but sampled in 8 kbps telemetry every 4.096 seconds. These parameters are *not* used in NASA image processing.

2) $W_{X,Y,Z}$ *(angular rate)* – angular increment ($\theta_{X,Y,Z}$) divided by 0.512 seconds. These parameters are *not* used in NASA image processing.

3) $E_{X,Y,Z}$ *(attitude error)* – desired attitude (based on the ephemeris) minus measured attitude (based on gyro and star tracker data); defined about the ACS reference axes; data in two's complement format; computed every 0.512 seconds, but sampled in 8 kbps telemetry every 4.096 seconds. These parameters are *not* used in NASA image processing.

4) *EPA1-4 (Euler parameters)* – defined in 5.4.7.2e; data in two's complement format; computed every 0.512 seconds, but sampled in 8 kbps telemetry every 4.096 seconds. These parameters also appear in PCD, but are scaled differently and are sampled at different times. These parameters are only used to intialize NASA image processing, but are estimated to result in approximately 10 arc second accuracies if used (in comparison to 1.5 arc second accuracies using DRIRU data, or 36 arc second accuracies with no attitude corrections).

5) $\theta_{BX,BY,BZ}$ *(gyro bias compensation)* – defined in 5.4.7.2d; data in two's complement format; estimated at each star sighting (up to once per minute), but sampled in 8 kbps telemetry every 16.384 seconds. These parameters also appear in PCD, but are scaled differently and are sampled at different times. In NASA image processing, one value (the *last* good value obtained) is selected for each processing interval (i.e. spacecraft imaging pass) and used in processing MSS data.

6) *CNGX,Y,Z (uncompensated gyro data)* – change in DRIRU channels occurring over the preceeding 0.512 second period; developed from 0.064 second DRIRU samples which are corrected for register overflow, low-pass filtered to 0.5 Hz if the filter is in use (FLTROFF = 1), subsampled 8:1, and then differenced; data in two's complement form. CNGX and CNGZ will normally indicate approximately 0 counts, and CNGY will normally indicate approximately 4480 counts (i.e. orbital pitch rate).

Table 22
Ephemeris Computation Telemetry Report 1

SYMBOL	DEFINITION	OBC REPORT	SAMPLES PER MAJOR FRAME	NUMBER OF BYTES	RANGE	UNITS	LSB WEIGHT
EOGBRF(1)	EARTH CENTERED INERTIAL (ECI) X-AXIS COMPONENT OF FLIGHT SEGMENT (FS) POSITION COMPUTED USING PREDICTED-FIT EPHEMERIS	13	4	4	±8.3886E6	METERS	$1/2^8$
EOGBRF(2)	ECI Y-AXIS COMPONENT OF FS POSITION COMPUTED USING PREDICTED-FIT EPHEMERIS	13	4	4	±8.3886E6	METERS	$1/2^8$
EOGBRF(3)	ECI Z-AXIS COMPONENT OF FS POSITION COMPUTED USING PREDICTED-FIT EPHEMERIS	13	4	4	±8.3886E6	METERS	$1/2^8$
EOGBVF(1)	ECI X-AXIS COMPONENT OF FS VELOCITY COMPUTED USING PREDICTED-FIT EPHEMERIS	13	4	4	±8	METERS/MILLISECOND	$1/2^{28}$
EOGBVF(2)	ECI Y-AXIS COMPONENT OF FS VELOCITY COMPUTED USING PREDICTED-FIT EPHEMERIS	13	4	4	±8	METERS/MILLISECOND	$1/2^{28}$
EOGBVF(3)	ECI Z-AXIS COMPONENT OF FS VELOCITY COMPUTED USING PREDICTED-FIT EPHEMERIS	13	4	4	±8	METERS/MILLISECOND	$1/2^{28}$

c. Spacecraft antenna characteristics

- Shaped-beam antenna
- Gain at 63.8 degrees from nadir (plus 7 dB)
- Gain at nadir (minus 9 dB)
- Spacecraft connection loss: 0.6 dB

d. Modulation scheme

- Unbalanced quadrature phase-shift keyed (UQPSK)
- MSS (15.0626 Mbps) data on the Q-channel
- TM (84.903 Mbps) data on the I-channel

e. Downlink spectrum: The TM data are PN-encoded on the spacecraft. Data are spread over approximately 170-MHz bandwidth.

9.1.1 Working Mode, Modulation, and Spectral Occupation

The Landsat X-band transmit link uses a UQPSK modulation format for transmitting TM and MSS data. The TM data are usually modulated on the "I" carrier channel, and the MSS data on the "Q" carrier channel with a 4 to 1 power split. There will be three operational modes that are as follows:

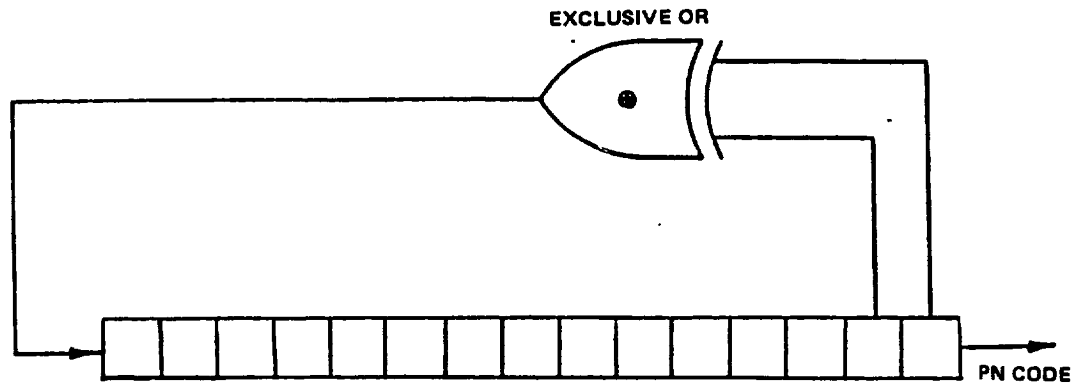
Mode	I-Channel	Q-Channel	Modulation
1	PN (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK
2	TM (84.903 Mbps)	TM (84.903 Mbps)	BPSK
3	TM (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK

The TM data are replaced with PN code for mode 1, in which only the MSS is operating. The PN code used to replace TM data is generated as shown in Figure 28a. In mode 2 when only the TM is operating, the MSS data may be replaced with TM data. In modes 2 and 3, the TM data are PN-encoded as defined in 5.4.5 within the instrument electronics. The MSS and TM are differentially encoded by converting from NRZ-L to NRZ-M for downlink transmission.

9.1.2 Output Filter Characteristics

A low-pass filter at the output of the TWT is planned to attenuate the TWTA second harmonic as well as the output noise to a level at which it will not degrade the Ku-band forward link receiver noise figure. A pre-TWTA four-pole 0.01-dB ripple Tschebyscheff filter with a matched bandwidth of 225 MHz is provided to meet power flux density restrictions. The X-band low-pass filter characteristics are as follows:

Bandwidth: ±84 MHz
Insertion loss: ≤0.15 dB
VSWR: 1.15:1



(No seed word utilized; any pattern other than all-zeros is acceptable)

Figure 28a. Generation of PN Code to Replace TM Data

Phase deviation from linearity: $\leq$0.25 deg over $\pm$84 MHz
Insertion loss variation: $\leq$0.05 dB over $\pm$84 MHz
Gain slope: $\leq$0.01 dB/MHz over $\pm$84 MHz
Rejection: $\geq$31 dB at 16.4 GHz; $\geq$14 dB at 13.775 GHz

9.2 LANDSAT S-BAND IMAGE DATA TRANSMISSION CHARACTERISTICS

The following information describes the Landsat S-band image data transmission characteristics:

a. Carrier frequency: 2265.5 MHz

b. Transmitter power: 10 watts

c. Spacecraft antenna characteristics

- Shaped-beam antenna
- Gain at 63.8 degrees from nadir (+2.5 dB)
- Gain at nadir (-8 dB)
- Spacecraft connection loss: 1.5 dB

d. Modulation scheme

- NRZ-L PCM/FM
- MSS 15.0626 Mbps (same as Landsats-1 through -3)
- Deviation: $\pm$5.6 MHz $\pm$5 percent

e. Downlink spectrum: MSS data are spread over approximately 20-MHz bandwidth.

9.3 LANDSAT S-BAND TELEMETRY DATA TRANSMISSION CHARACTERISTICS

The S-band telemetry will be commanded on in response to a foreign station's request for telemetry data to support their MSS image data reception by either S-band or X-band. The following information describes the Landsat S-band telemetry data transmission characteristics:

a. Frequency: 2287.5 MHz

b. Effective isotropic radiation power: +3.2 dBW

c. Modulation scheme:

- 8-kbps data (1.024-MHz subcarrier): Biphase-S/PSK/PM
- High-rate data (PCD, OBC, STR to GSTDN): Biphase-S/PM
- Ranging signals (to GSTDN): PM
- Carrier modulation index for 8 kbps telemetry: 0.8 rad with other signals; 1.6 rad alone

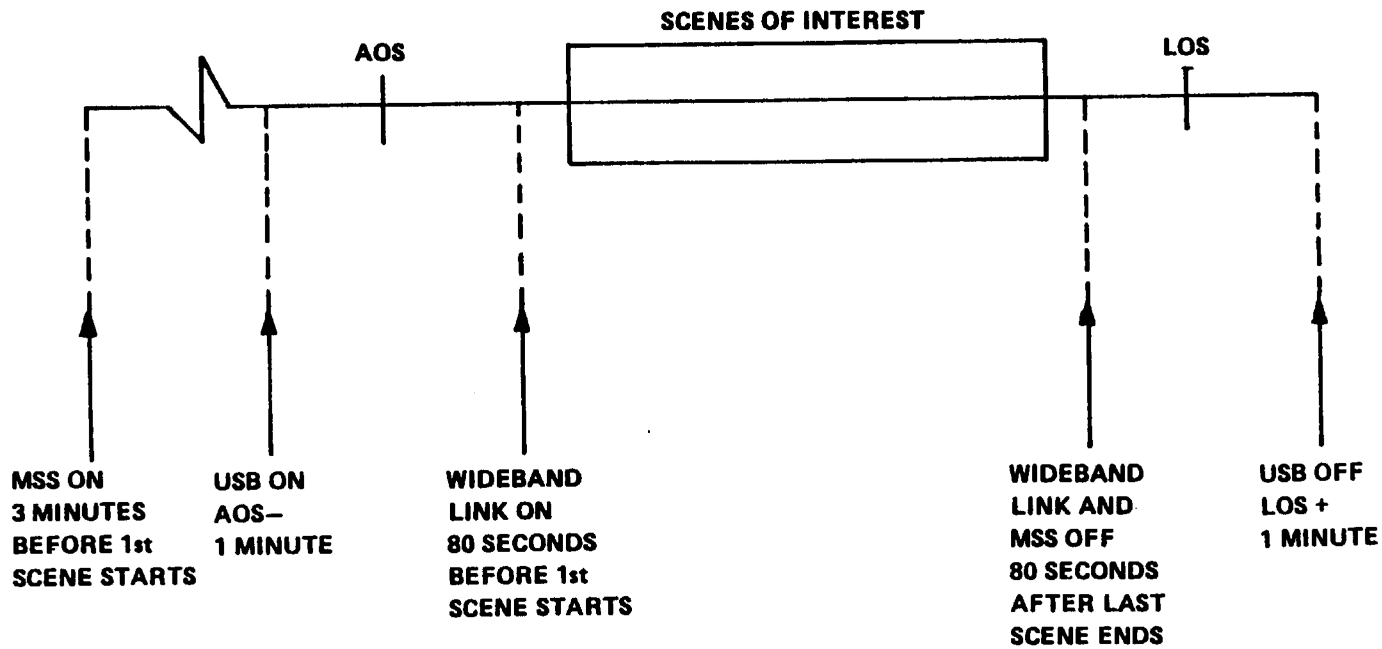
d. Frequency stability and aging temperature stability:

- Combined effects over 1 year: ± 3.8 parts per 10^6
- Short-term stability: the rms fractional deviation for a 3-minute period, measured with a 1.0-second integration time shall not exceed 3×10^{-9}.

e. Downlink spectrum: Data are spread over approximately 3-MHz bandwidth.

9.4 LANDSAT X-BAND AND S-BAND COMMUNICATIONS AVAILABILITY TO FOREIGN GROUND STATIONS

Foreign ground stations can acquire TM video data by the X-band link only. PCD can be acquired by the X-band (in TM video). S-band (32-kbps data link) transmission of PCD to foreign ground stations is not planned. MSS video data can be acquired by the X-band link in addition to the S-band link, as is currently the case with Landsat-2 and Landsat-3. MSS telemetry data can be acquired on the S-band 8-kbps link. If required, S-band and X-band communications links can be operated simultaneously to satisfy foreign ground station coverage requirements for common areas. Simultaneous S-band and X-band image data transmission to one station will not be supported. Each Landsat Flight Segment has been designed to transmit a cumulative total of 100 daytime and 50 night thematic mapper scenes to participating user ground stations. A typical station pass transmission schedule is shown in Figure 29.



1 USB = UNIFIED S-BAND (S-BAND TELEMETRY) AOS = ACQUISITION OF SIGNAL
PBM = PASS BRIEFING MESSAGE LOS = LOSS OF SIGNAL

2 AOS AND LOS = 0° ELEVATION FROM STATION LOCATION

3 PBM GIVES: AOS AND LOS AS USB ON AND OFF TIMES
START OF 1st SCENE AS WIDEBAND ON TIME
END OF LAST SCENE AS WIDEBAND OFF TIME

Figure 29. Typical Ground Station Pass

9.5 DOWNLINK CARRIER FREQUENCY STABILITY

Preliminary downlink carrier frequency stability for the X-band, S-band telemetry, and S-band image data communications links to foreign ground stations are as follows:

a. Landsat S-band telemetry data transmission frequency stability: ±0.0004 percent inclusive of initial frequency setting, aging, and temperature stability effects over 1 year

b. Landsat X-band transmission initial setting accuracy: 82125 GHz ±0.005 percent; frequency stability: ±0.0004 percent after 3 years in space

c. Landsat S-band image data transmission: ±0.0005 percent inclusive of initial frequency setting, aging, and temperature effects after 3 years in space

10. CHANNEL AND PROCEDURES FOR PROVIDING CALIBRATION DATA TO FOREIGN STATIONS

NASA/GSFC supplies calibration data to members of the Landsat Ground Station Operations Working Group (LGSOWG) only as authorized by NASA Headquarters. The following calibration data have been provided in the past to approved LGSOWG members:

a. Prelaunch mirror velocity profile
b. Postlaunch mirror velocity profiles as available
c. Prelaunch detector response curves

11. TELEMETRY TIME SIGNALS--ONBOARD CLOCK RESETTING PROCEDURE

The time of the onboard clock shall be accurate to ±20 milliseconds relative to Universal Time Coordinated (UTC). A daily update is expected to be adequate for maintaining this clock accuracy. Time updates will not be performed during MSS or TM data acquisitions. The daily update procedure is very brief and will be scheduled so as to not interfere with or preclude the acquisition of any desired data.

At the change of the calendar year, a clock reset operation will be performed (in order to recycle the day of year counter). This reset operation will require a period of up to eight hours in which normal MSS and TM operations will be suspended. The reset period will normally be scheduled to begin several hours before midnight GMT on December 31. Foreign ground stations will be advised of the schedule for this operation via Telex message. Any special requirements for coverage during the reset operation period should be submitted well in advance of December 31 to allow adequate time for planning.

APPENDIX A

MULTISPECTRAL SCANNER DATA FORMAT

APPENDIX A

MULTISPECTRAL SCANNER DATA FORMAT

A1. GENERAL DESCRIPTION

A1.1 MULTISPECTRAL SCANNER FORMAT

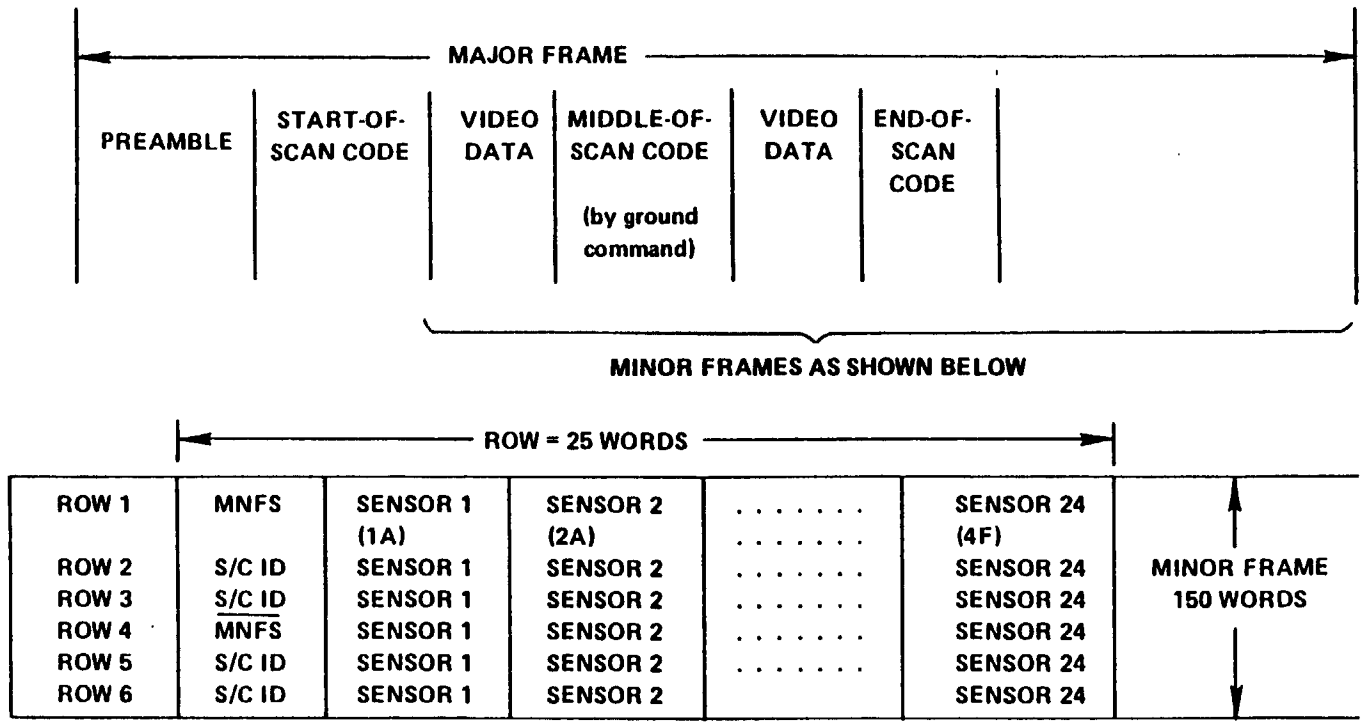
The Multispectral Scanner (MSS) format described in the following paragraphs defines the serial bit stream following bit synchronization (i.e., input to high-density tape recorders). The MSS is capable of operating in two basic modes (compressed and linear) and may be operated at different gains, as shown in Table A-1. The data format does not vary depending on the mode. NASA plans to routinely operate the MSS in the compressed mode with all bands at low gain (1X), and has no plans to operate individual bands at high gain (3X).

A2. BIT SYNCHRONIZATION OUTPUT FORMAT

The serial data stream can be observed after bit synchronization on the ground before any further processing. Thus, it agrees with the MSS MUX output on the Landsat spacecraft. The data, after being encoded by the MUX, are in the format shown in Figure A-1. This format, which defines the details of one major frame of data containing 184,320 6-bit words, corresponds to one scan of the MSS scan mirror. Figure A-1 also shows a typical minor frame, 150 words output serially during the sensor data interval, that contains the 6- by 25-word matrix. The data rate is approximately 15.06 Mbps, which agrees with a data-word rate of approximately 2.5 by 10^6 words per second. The five segments of the major-frame format plus the calibration data format are discussed in the following subsections. Figure A-2 and Tables A-2 and A-3 are provided as reference for timing, coding, and other specifics.

Table A-1
Possible MSS Operating Configurations

	MUX Mode		Gains (selectable by band)
	Linear	Compressed	
Band 1	Linear	Compressed	1X or 3X
Band 2	Linear	Compressed	1X or 3X
Band 3	Linear	Compressed	1X
Band 4	Linear	Linear	1X



MNFS = MINOR FRAME SYNC CODE

NOTE: THE SAMPLING SEQUENCE SHALL BE 1A, 2A, 1B, 2B,...3F, 4F
S/C ID FOR LANDSAT-4 = 001100
FOR LANDSAT-5 = 100100 ± 2
FOLLOWING THE START-OF-SCAN CODE ROWS 1 AND 2 OF THE FIRST MINOR FRAME CONTAIN 49 WORDS OF TIME-CODE DATA IN PLACE OF SENSOR DATA.

Figure A-1. Multiplexer Output Data Format

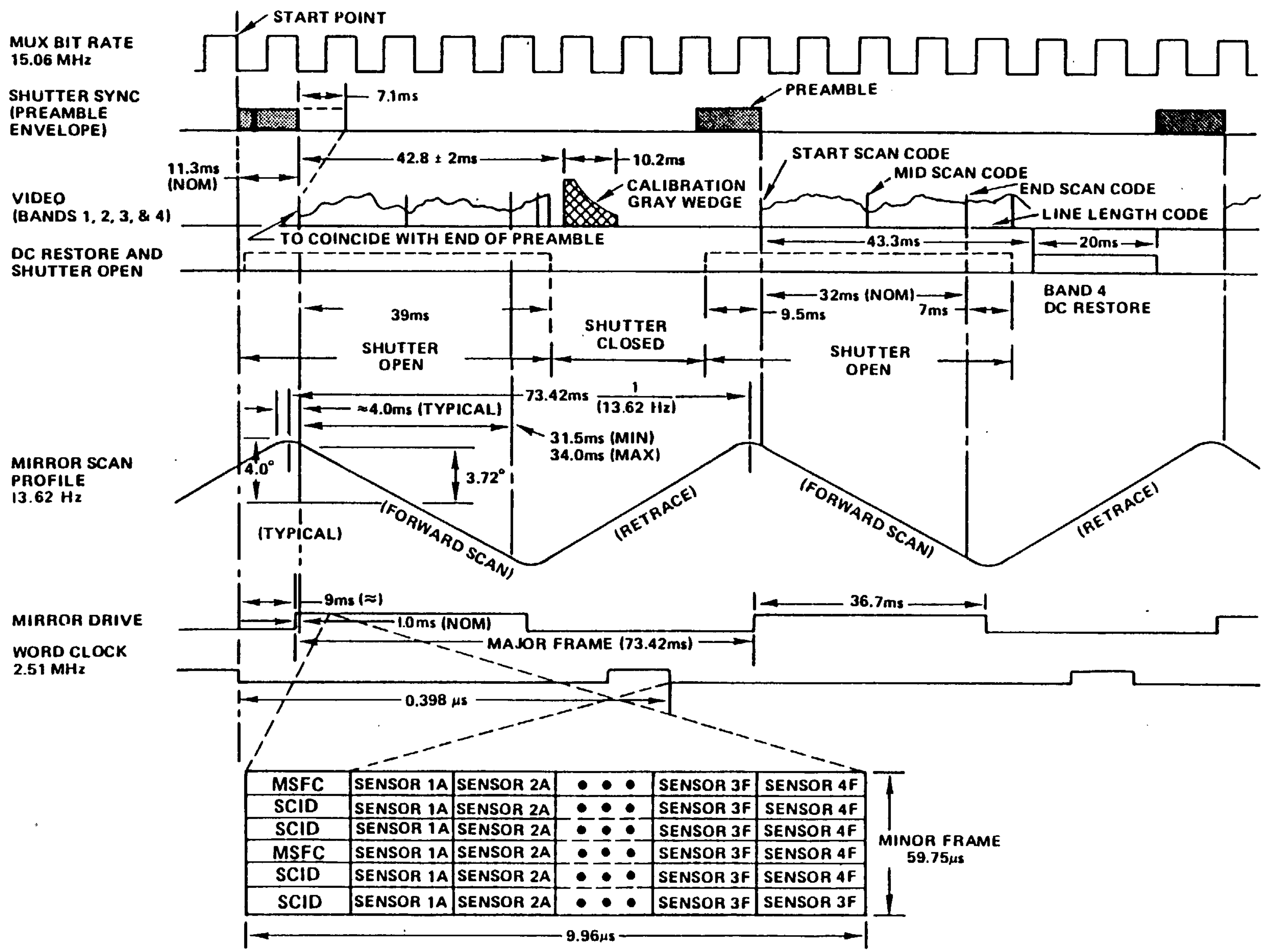


Figure A-2. Multiplexer Data Timing and Format

Table A-2
Multispectral Scanner Multiplexer and Bit Sync Format

Item	Coding (6-bit word)	Time Duration	Field Size
Preamble	000111	11.4 ± 7 msec	28619 ± 17573 words
Start-Scan Code	111000	0.398 μsec	1 word
Minor Frame Sync	001011	0.398 μsec	1 word
Time Code	Logic '1's and '0's (110011 and 001100)	19.52 μsec (preempts scene data at beginning of 1st minor frame)	49 words
Scene Data (active scan)	Data*	32.75 ± 1.25 msec (beginning at start of scan)	~548 ± 21 minor frames
Mid-Scan Code (in lieu of scene data)	100 Black (001100) 100 White (110011)	79.67 μsec	200 words
End-Scan Code (preempts scene data)	100 Black (001100) 100 White (110011)	79.67 μsec	200 words
Shutter Obscuration	Data*	24.9 ± 2 msec (begins 39 msec after start of scan; may extend into next major frame)	~417 ± 34 minor frames
Calibration Wedge (on alternate scans during obscuration)	Data*	10.2 ± 2 msec (begins 42.8 ± 2 msec after start of scan)	~171 ± 34 minor frames
DC Restore (Band 4 on non-cal wedge scans)	~Black (001100)	20.0 ± 2 msec (begins 42.8 msec after start of scan; may extend into next major frame)	~335 ± 34 minor frames

*Binary: 0 to 63 levels with center two bits inverted (e.g., level 6 = 001010).

Table A-3
Multispectral Scanner Data Format

Event	Nominal Start Minor Frame Count	Nominal End Minor Frame Count	Explanatory Notes
Start of Scan	0	0	Note 1
Time Code	1	1	Note 2
Scene Data	1	549	Note 3
End of Scan	549	End of Scan +1 or +2	Note 3
Shutter Obscuration	653	Obscuration +417	Note 4
Calibration Wedge	Obscuration +64	Obscuration +235	Note 4
DC Restore	End of Scan +177	End of Scan +512	Note 5
Preamble (start of next minor frame)	1038	1229	

[1]Start-of-scan pulse initiates start-scan code, then 1st minor frame begins.

[2]Time code preempts scene data and spacecraft ID in 49 words following MNFS of 1st minor frame.

[3]Scene data follows time code data in 1st minor frame, and continues until end-of-scan pulse initiates end-scan on word boundary. End-scan code ends after 200 word times, one or two minor frames later.

[4]Shutter obscuration synchronized to start-of-scan pulse; calibration wedge appearance based on shutter rotation, on alternate scans.

[5]DC restore timed from end-of-scan pulse on non-calibrated scans.

A2.1 PREAMBLE

The start of the preamble defines the start of the major frame. The pattern is 000111 repeated at the data word rate. The preamble is terminated at the end of the word period during which the start of scan monitor pulse is received from the scanner.

A2.2 START-OF-SCAN CODE

The single word following the termination of the preamble is the start of the scan (SMC-1) code pattern, 111000, which appears in the data stream immediately after a preamble word. Thus, an indication of the line start (i.e., beginning of active scan) is the appearance of six adjacent ones.

A2.3 VIDEO DATA

Following the start-of-scan code, the MSS MUX begins to transmit data that are grouped in minor frames of 150 words (i.e., six rows of 25 words each) as shown in Figure A-1. The minor-frame synchronization (MNFS) code is 001011 and occurs as the first word in row 1. The complement of the MNFS occurs as the first word in row 4 of each minor frame. The time-code data from the spacecraft clock are inserted in word positions 2 through 49 of rows 1 and 2 of the first minor frame of each scan in place of sensor data as shown in Figures A-3 and A-4. Figure A-4 shows the placement of various units of the BCD time code in different scans. The total code requires that two scan be inserted, and the format alternates back and forth every two scans. Figure A-3 relates the time-code clock output to the MUX-generated envelope and the time-code input to the MUX and shows their relationship within the first minor frame of each scan. Although the spacecraft clock provides a 49-bit NRZ-L time code to the MUX, the 49th bit of the code is not accepted by the MUX. Note the time-code envelope in Figure A-3. Also note that spacecraft clock bit 25 is a dummy bit. As for sensor data, a time-code data zero bit is encoded by the MUX as output data bits 001100, and a time-code data one bit as 110011.

Word positions 2 through 25 in all other rows contain encoded sensor data words from Bands 1 through 4. The signal from each band is converted to a binary code in which 000000 represents the least positive voltage levels. After conversion to their binary equivalent, the data are encoded in the MUX by inverting data bits 3 and 4 in each sensor data word (i.e., binary level 000000 will be encoded as 001100). Sensor data are transmitted with the MSB first.

A2.4 MIDDLE-OF-SCAN CODE

When operated in the midscan indicator ON mode, the MUX preempts transmission of sensor data on receipt of the middle-of-scan monitor pulse from the scanner and transmits the middle-of-scan code.

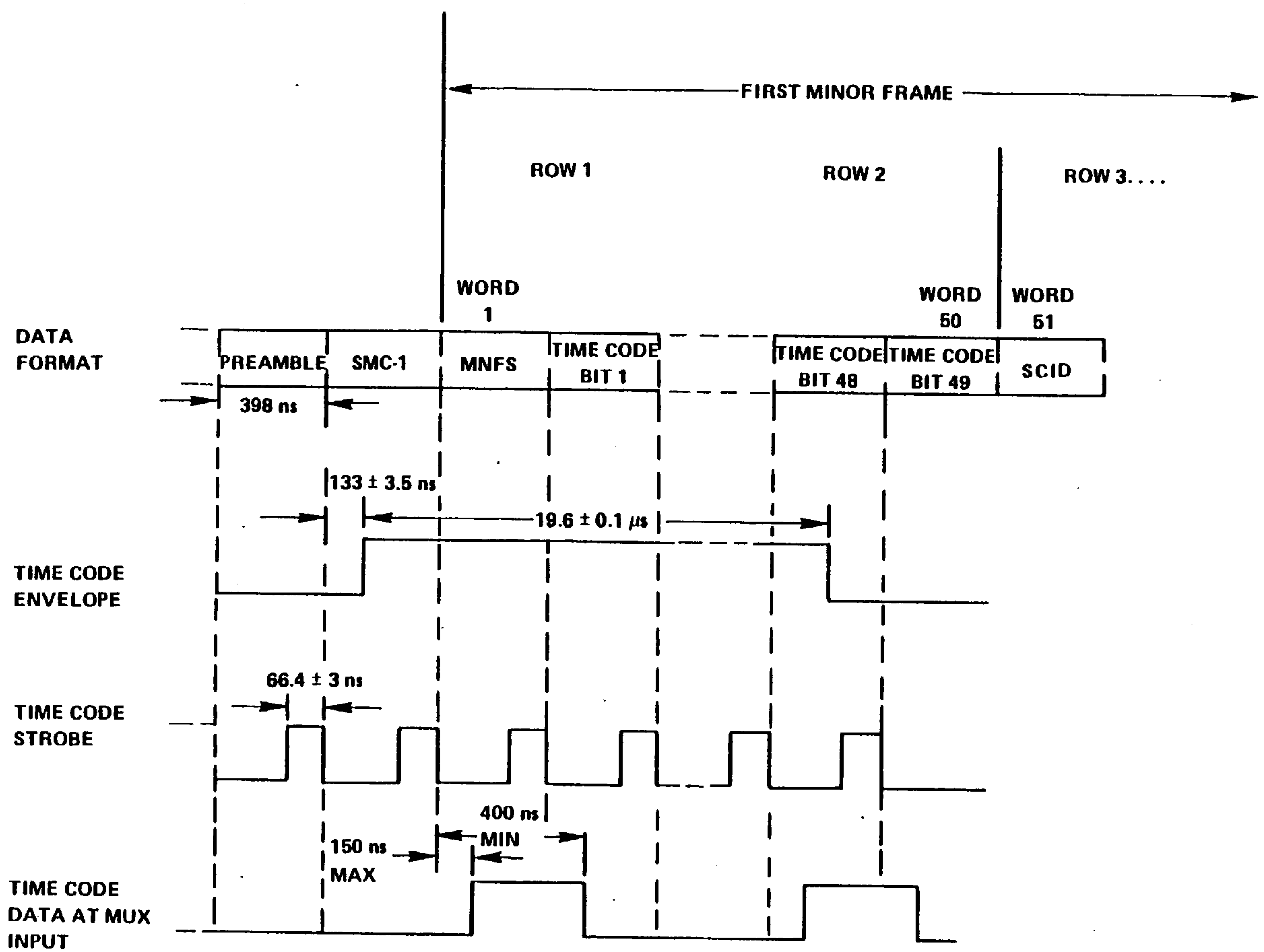
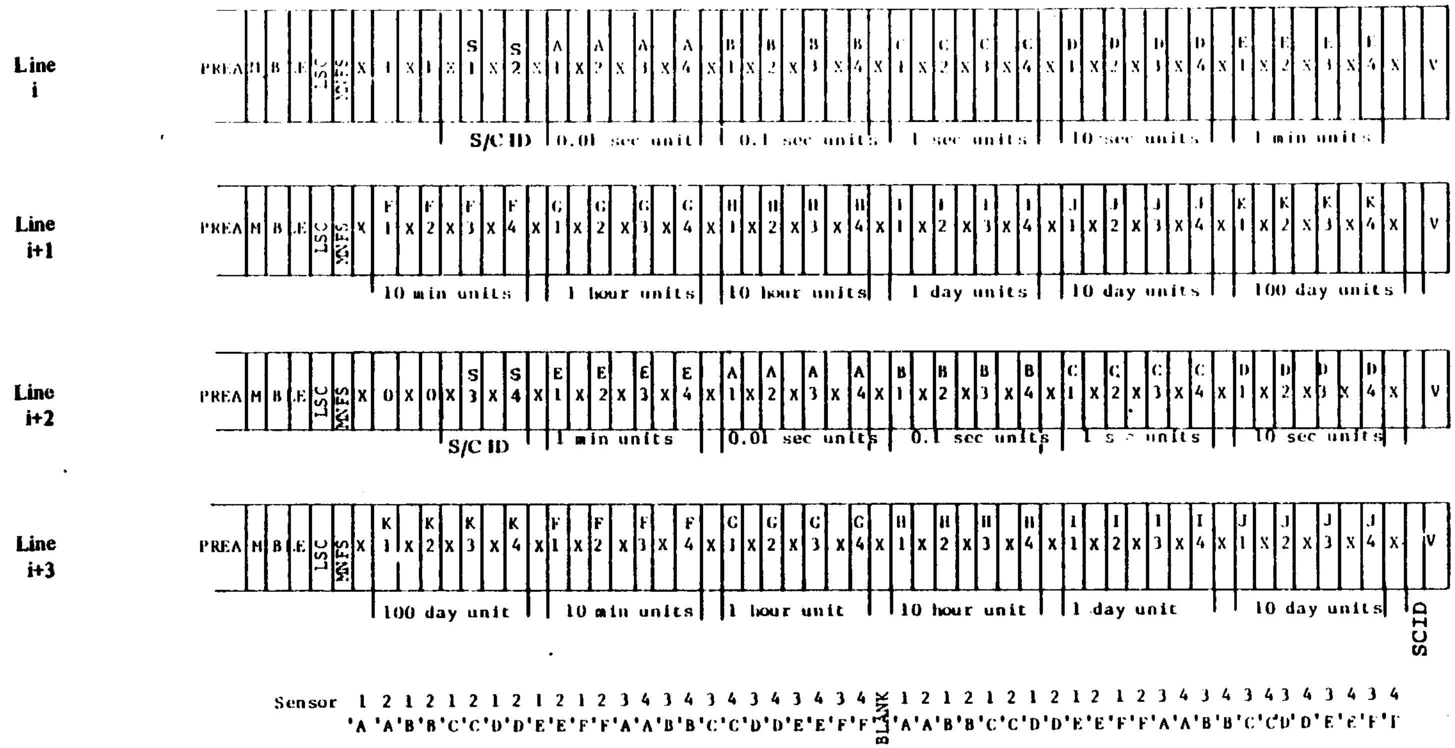


Figure A-3. Relationship of Time Code Signals to Multiplexer Output



Time-code
update every
i+2n lines
where n = 1,2,3...
SCID

NOTES:

1. LSB FIRST IN TIME
2. CODING

	0	1
MUX. INTERNAL	000000	111111
MUX. OUTPUT	001100	110011

3. NO DATA DURING TIME CODE – X
4. VIDEO DATA – V
5. LINE START CODE – LSC
6. XXXX – SPACES
7. S1-S4 = SPACECRAFT ID AS FOLLOWS:
   1110 = LANDSAT-4
   1101 = LANDSAT-5
8. X = UNDEFINED
9. SCID = EMBEDDED SPACECRAFT ID
   001100 = LANDSAT-4
   100100 ± 2 = LANDSAT-5

NOTATION

A = HUNDREDTHS OF SECONDS
B = TENTHS OF SECONDS
C = UNITS SECONDS
D = TENS SECONDS
E = UNITS MINUTES
F = TENS MINUTES
G = UNITS HOURS
H = TENS HOURS
I = UNITS DAYS
J = TENS DAYS
K = HUNDREDS DAYS

Figure A-4. MSS Time Code Format for Landsat

Beginning with the word period immediately following the receipt of the pulse, the MUX transmits the encoded equivalent of the black-sensor level (i.e., 0.00 volt input, code 001100) for the next 100-word periods. In the subsequent 100-word periods, the encoded equivalent of the white-sensor level (i.e., 4.0 volts input, code 110011) is transmitted. In the next word period, sensor data resume. (Note that only sensor data are preempted; minor frame synchronization codes are inserted in their proper locations but are included in the count of word periods.) When operated in the midscan indicator OFF mode, the MUX ignores the middle-of-scan monitor pulse and continues to transmit sensor data from the scanner. NASA plans to use the midscan code to develop and/or validate mirror velocity profiles and mirror scan repeatability. NASA intends to use this mode infrequently on a noninterference basis with foreign acquisition requirements.

A2.5 END-OF-SCAN CODE

On receipt of the end-of-scan monitor pulse from the scanner, the MUX preempts transmission of sensor data from the scanner and transmits the end-of-scan code. This code is identical to the black-and-white level code patterns of the middle-of-scan code. After transmission of end-of-scan code (200-word periods), sensor data resume until the end of the major frame.

A2.6 INTERNAL CALIBRATION DATA

Whereas the preceding five subsections cover MUX data output patterns, internal calibration differs in that the MUX does not control it. Calibration data appear in the serial data stream during every other retrace interval (i.e., between the end-of-scan code and the beginning of preamble). During the retrace interval, the scan mirror makes the transit from east to west, a shutter wheel closes off the optical fiber view to the Earth, and a light source (calibration lamp) is projected onto the fibers through a variable neutral-density filter on the shutter wheel. This process introduces a calibration wedge into the video data stream of Bands 1 through 4 during this retrace interval. The nominal shape of the calibration or gray wedge is shown in Figure A-5. The actual shape and level varies somewhat for the detectors in the various spectral bands. The calibration wedge is about 10.2 ms in total duration. Wedge density levels (digital) decrease from 63 to 0 and the wedge appears once every 147 ms. Assuming that the calibration lamp intensity is constant, it is possible to obtain a check of the relative radiometric levels and to equalize gain changes that may occur in the six detectors of a spectral band.

Since internal calibration is a function of the rotating shutter and calibration lamp and is not controlled by the MUX, it does not occur at the exact word position in the data stream of every other scan retrace. The purpose of the calibration wedge is to determine that the calibration lamp, neutral-density wedge, optics train,

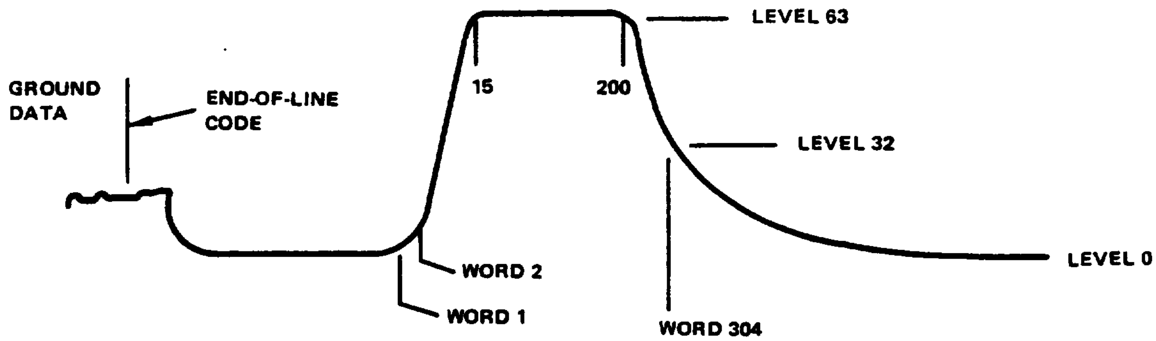


Figure A-5. Nominal Calibration Wedge Curve

and radiometer visual channels are providing a calibration lamp versus time that can be processed to provide the required number of gray-scale levels of descending half-power levels. Thus, during every other scan retrace, about 10 ms of minor frames contain calibration data in the sensor data words. Beginning about 11 ms after end-of-line on noncalibration retraces, the sensors output a black level derived from the detectors looking at a dark surface on the shutter. As with all other sensor data words, the internal calibration data are encoded by inverting the middle two bits. Figure A-6 shows details within the scanner related to internal calibration and Band 4 dc restoration.

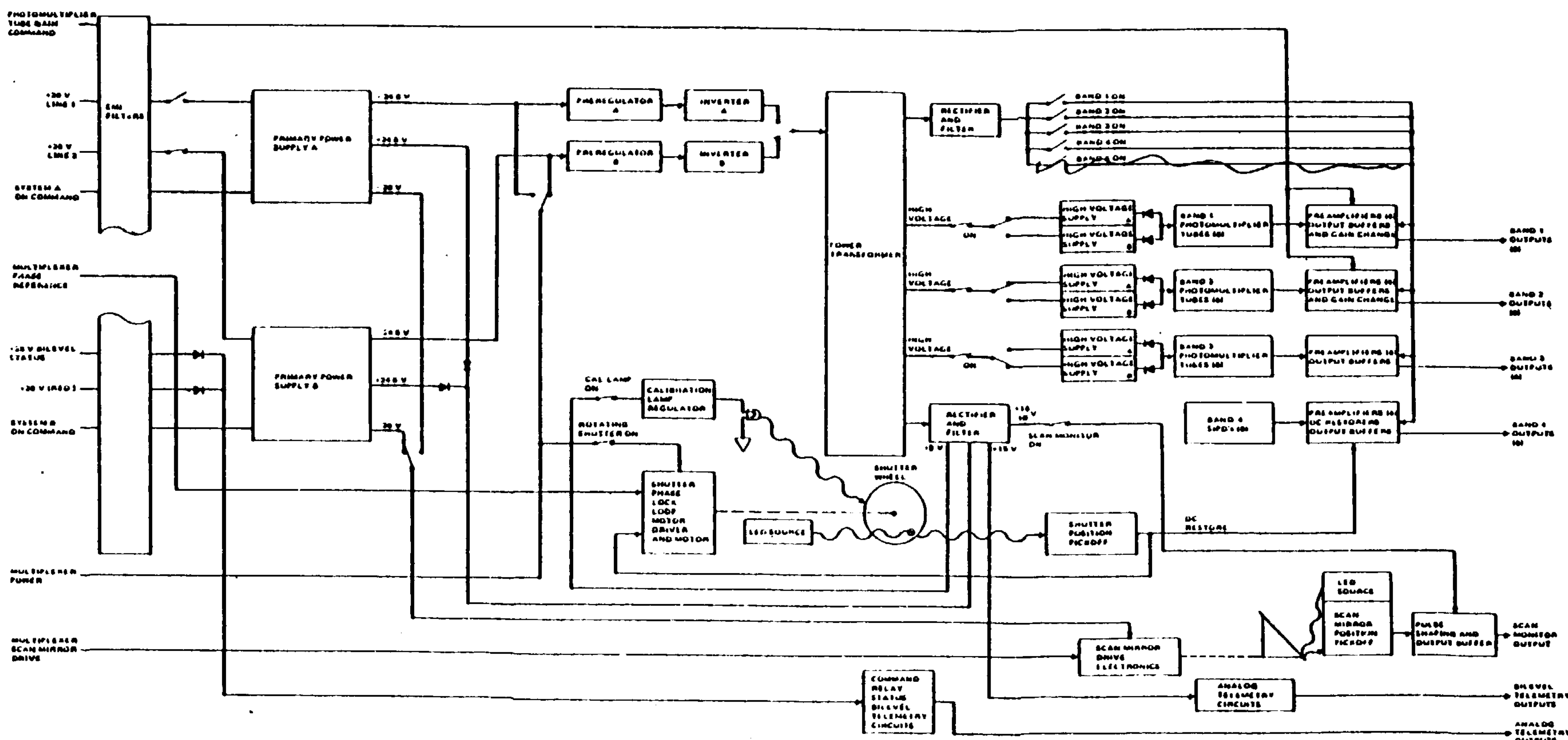


Figure A-6. Scanner Functional Block Diagram

APPENDIX B

MSS DATA PROCESSING CONSTANTS

APPENDIX B

MSS DATA PROCESSING CONSTANTS

B1. SPACECRAFT AND SENSOR CONSTANTS

Tables B-1 and B-1a list the values for certain spacecraft and sensor constants required in ground processing. The MSS band-to-band offsets as established for use in NASA processing are given for Bands 2, 3, and 4 with an implied zero for Band 1. The offset is a number such that when added to a "sampling time delay" for a detector of that band, the result is an offset in pixels for that detector from a fictitious detector for which the NASA resampling matrices were formed. Thus 27 numbers are given: 3 "band-to-band" offsets and 24 "sampling time" delays. (A set of six is repeated for each band.) This particular partition was selected to satisfy certain historically acceptable formats. The basic detector layout for the Landsat-4/-5 MSS is the same as that for the Landsats-1,-2, and -3 instruments. Decompression data are provided in Tables B-2 and B-2a.

Table B-1
Landsat-4 Spacecraft and Sensor Constants

Data Description	Values
Nominal number of pixels per input line	3240
Nominal scale of input interpixel distance in meters per pixel	57
Nominal scale of input interline distance in meters per pixel	82.7
Nominal spacecraft altitude in meters	705300
Nominal input swath width in meters	185000
The prelaunch mirror scan profile for MSS as a function of time (t) from scan line start:	

$$\ell = 2 \cdot A \cdot e^{-\beta t_n} \cdot \sin W (t_o + t_n)$$

with $t_n = \frac{P_{NOM}}{P} \cdot t$

and

ℓ = scan angle, rad.

Table B-1
Landsat-4 Spacecraft and Sensor Constants (Continued)

Data Description	Values
A = harmonic amplitude	0.233391 rad
β = damping constant	0.00739/sec
P = active scan time (SMC-1 $\longrightarrow$ SMC-3)	
P_{NOM} = nominal active scan time	32.3 msec
W = mirror frequency	17.4987 rad/sec
t_0 = start time for scan relative to center of scan angle	-16.148 ms
MSS maximum mirror angle in radians	0.2603
Time between successive MSS mirror sweeps in seconds	0.07342
Data bit rate	15.0626304 Mbps
MSS sampling delay consists of 24 values, (one for each detector) measured in input image along-scan pixel units. The MSS sampling delay constants will appear in the following order:	
Band 1 Detector 1	-2.720805
Detector 2	-2.800665
Detector 3	-2.880525
Detector 4	-2.960385
Detector 5	-3.040245
Detector 6	-3.120105
Band 2 Detectors 1-6 Band 3 Detectors 1-6 Band 4 Detectors 1-6 — Same values as for Band 1 Detectors 1-6, respectively	
MSS band-to-band offsets with respect to Band 1 (3 values: one each for Bands 2, 3 and 4) measured in input image along-scan pixel units	Band 2 = 1.95007 Band 3 = 3.89084 Band 4 = 5.84091

Table B-1a
Landsat-5 Spacecraft and Sensor Constants

Data Description	Values
Nominal number of pixels per input line	3233
Nominal scale of input interpixel distance in meters per pixel	57
Nominal scale of input interline distance in meters per pixel	82.7
Nominal spacecraft altitude in meters	705300
Nominal input swath width in meters	185000
The prelaunch mirror scan profile for MSS as a function of time (t) from scan line start: $$\ell = 2 \cdot A \cdot e^{-\beta t_n} \cdot \sin W (t_o + t_n)$$ with $t_n = \frac{P_{NOM}}{P} \cdot t$ and ℓ = scan angle, rad.	

Table B-1a
Landsat-5 Spacecraft and Sensor Constants (Continued)

Data Description	Values
A = harmonic amplitude	0.2379662 rad
β = damping constant	0.00695558/sec
P = active scan time (SMC-1 → SMC-3)	
P_{NOM} = nominal active scan time	32.2 msec
W = mirror frequency	17.22 rad/sec
t_0 = start time for scan relative to center of scan angle	-16.098 ms
MSS maximum mirror angle in radians	0.2605
Time between successive MSS mirror sweeps in seconds	0.07342
Data bit rate	15.0626304 Mbps
MSS sampling delay consists of 24 values, (one for each detector) measured in input image along-scan pixel units. The MSS sampling delay constants will appear in the following order:	
Band 1 Detector 1	-2.720805
Detector 2	-2.800665
Detector 3	-2.880525
Detector 4	-2.960385
Detector 5	-3.040245
Detector 6	-3.120105
Band 2 Detectors 1-6, Band 3 Detectors 1-6, Band 4 Detectors 1-6: Same values as for Band 1 Detectors 1-6, respectively	
MSS band-to-band offsets with respect to Band 1 (3 values: one each for Bands 2, 3 and 4) measured in input image along-scan pixel units	Band 2 = 1.95007 Band 3 = 3.89084 Band 4 = 5.84091

Table B-2
Landsat-4 MSS Decompression Table

Compressed Quantum Level	Equivalent Linear Quantum Level		Compressed Quantum Level	Equivalent Linear Quantum Level	
	Bands 1&3	Band 2		Bands 1&3	Band 2
0	0	0	32	42	42
1	1	1	33	44	44
2	2	2	34	46	46
3	3	2	35	48	48
4	3	3	36	50	49
5	4	4	37	52	51
6	5	5	38	54	54
7	6	6	39	56	56
8	7	7	40	59	59
9	8	8	41	62	61
10	9	9	42	65	64
11	10	10	43	67	67
12	11	11	44	70	70
13	12	12	45	73	73
14	13	13	46	76	76
15	14	14	47	79	79
16	16	16	48	82	81
17	17	17	49	85	84
18	18	18	50	88	87
19	20	19	51	91	90
20	21	21	52	94	93
21	22	22	53	96	96
22	24	24	54	99	99
23	26	26	55	102	102
24	27	27	56	105	105
25	29	29	57	108	108
26	31	31	58	111	111
27	33	33	59	114	114
28	34	34	60	117	117
29	36	36	61	120	120
30	38	38	62	123	123
31	40	40	63	127	127

Table B-2a
Landsat-5 MSS Decompression Table

Compressed Quantum Level	Equivalent Linear Quantum Level		Compressed Quantum Level	Equivalent Linear Quantum Level	
	Bands 1&3	Band 2		Bands 1&3	Band 2
0	0	0	32	42	42
1	1	1	33	44	44
2	1	2	34	46	46
3	2	2	35	48	48
4	3	3	36	50	49
5	4	4	37	52	51
6	5	5	38	54	53
7	6	6	39	56	56
8	7	7	40	59	59
9	8	8	41	61	61
10	9	9	42	64	64
11	10	10	43	67	67
12	11	11	44	70	70
13	12	12	45	72	73
14	13	13	46	75	76
15	14	15	47	78	78
16	16	16	48	81	81
17	17	17	49	84	84
18	18	18	50	87	87
19	19	19	51	90	90
20	21	21	52	93	93
21	22	22	53	96	96
22	24	24	54	99	99
23	25	25	55	102	102
24	27	27	56	105	105
25	29	29	57	108	108
26	31	31	58	111	111
27	32	32	59	114	114
28	34	34	60	117	117
29	36	36	61	120	120
30	38	38	62	123	123
31	40	40	63	127	127

B2. CALIBRATION WEDGE WORD COUNT VALUES

Tables B-3 and B-3a present the number of pixels from the midpoint of the calibration wedge leading edge to the point at which each of six values are to be extracted for use in gain and offset calculations. Separate table segments are provided for each mode of sensor operation (high gain/low gain, use of prime/redundant calibration source lamp). Within each segment, sets of six word count values are provided for each band; and each set applies to all detectors within the band.

Table B-3
Landsat-4 Calibration Wedge Word Count Values

	Calibration Wedge Word Count* For Locating Sample Number:					
• Lamp A (Prime)						
High Gain:	1	2	3	4	5	6
Band 1	470	480	490	500	920	930
Band 2	580	590	600	610	950	960
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
Low Gain:						
Band 1	230	240	250	260	810	820
Band 2	340	350	360	370	880	890
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
• Lamp B (Redundant)						
High Gain:						
Band 1	470	480	490	500	920	930
Band 2	580	590	600	610	950	960
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760

Table B-3
Landsat-4 Calibration Wedge Word Count Values (Continued)

Low Gain:						
Band 1	230	240	250	260	810	820
Band 2	340	350	360	370	880	890
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760

*Number of pixels (words), counting from the first pixel of the leading edge of the cal. wedge which has a value 32, to the location of each of the six word samples to be extracted from the wedge.

B3. NOMINAL CALIBRATION QUANTUM LEVEL VALUES

Tables B-4 and B-4a present the nominal digital values that can be expected at each calibration wedge location defined in Tables B-3 and B-3a. Separate table segments are provided for each combination of sensor mode (high/low gain, use of prime/redundant calibration source lamp) and signal amplifier mode (linear/compressed). Within each segment, radiance values are provided for each word count value of each detector.

B4. OFFSET AND GAIN COEFFICIENTS (C_i' and D_i' Values)

Tables B-5, B-5a, B-6, B-6a, B-7, B-7a, B-8, and B-8a present the regression coefficients used with calibration wedge radiance values (which are extracted at locations defined by Tables B-3 and B-3a) to calculate the gain and offset values that describe the radiance calibration function for each detector. Each table describes a mode of sensor operation (high/low gain, use of prime/redundant calibration source lamp). Within each table, separate segments are provided for each detector of each band. Each segment contains an offset coefficient value and a gain coefficient value for each of the six calibration quantum level values to be extracted from the calibration wedge portion of the MSS data, normalized to the at-launch R_{min}/R_{max} values (as defined in Tables B-11 and B-11a):

$$C_i' = C_i + R_{min} * D_i$$

$$D_i' = (R_{max} - R_{min}) * D_i$$

Multiplicative and additive modification values (M's and A's) have been developed to further adjust the radiometric calibration functions defined by the data provided in Tables B-3 through B-8a. These values are intended to be applied as an additional step in developing gain and bias values from calibration wedge data.

Table B-3A
Landsat-5 Calibration Wedge Word Count Values

- Lamp A (Prime)

High Gain:

	Calibration Wedge Word Count* for Locating Sample Number:					
	1	2	3	4	5	6
Band 1	530	540	550	560	950	960
Band 2	630	640	650	660	950	960
Band 3	430	440	450	460	920	930
Band 4	390	400	410	420	820	830

Low Gain:

	1	2	3	4	5	6
Band 1	290	300	310	320	850	860
Band 2	400	410	420	430	920	930
Band 3	430	440	450	460	920	930
Band 4	390	400	410	420	820	830

- Lamp B (Redundant)

High Gain:

	1	2	3	4	5	6
Band 1	530	540	550	560	950	960
Band 2	630	640	650	660	950	960
Band 3	430	440	450	460	920	930
Band 4	390	400	410	420	820	830

Low Gain:

	1	2	3	4	5	6
Band 1	290	300	310	320	850	860
Band 2	400	410	420	430	920	930
Band 3	430	440	450	460	920	930
Band 4	390	400	410	420	820	830

*Number of pixels (words), counting from the first pixel of the leading edge of the cal. wedge which has a value ≥32, to the location of each of the six word samples to be extracted from the wedge.

Table B-4
Landsat-4 Nominal Calibration Record

1st Detector of Band						2nd Detector of Band						3rd Detector of Band						4th Detector of Band						5th Detector of Band						6th Detector of Band						
1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	1st Word Count					Last Word Count	
ACTIVE DETECTOR STATUS: AAAAAAAAAAAAAAAAAAAAAAAA																																				
CAL WEDGE (HIGH GAIN, LINEAR, LAMP A)																																				
44	42	40	38	2	2	45	42	40	38	2	2	46	44	42	40	2	2	45	42	41	40	2	2	44	42	40	38	2	2	45	44	41	40	2	2	Band 1
42	40	36	34	2	1	45	42	40	37	2	1	38	35	33	31	1	1	40	37	35	33	2	1	41	39	36	34	2	1	42	39	37	36	2	1	Band 2
45	43	40	38	3	3	46	43	41	39	3	3	47	45	43	40	3	3	45	42	40	38	3	3	46	42	40	38	3	2	46	43	41	38	3	2	Band 3
52	48	46	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (LOW GAIN, LINEAR, LAMP A)																																				
50	47	45	43	2	2	50	47	45	43	2	2	52	49	47	44	2	2	51	48	45	43	2	2	49	46	44	42	2	2	50	48	46	43	2	2	Band 1
50	47	44	42	2	2	54	50	48	45	2	2	46	43	41	39	2	2	48	45	42	40	2	2	50	47	45	42	2	2	51	48	45	43	2	2	Band 2
45	43	40	38	3	3	46	43	41	39	3	3	47	45	43	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	38	3	2	Band 3
52	48	46	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (HIGH GAIN, COMPRESSED, LAMP A)																																				
47	46	44	43	4	3	48	46	45	44	5	4	49	48	46	45	5	4	49	48	46	45	5	4	43	42	41	40	5	3	47	46	44	43	5	3	Band 1
46	44	42	41	5	3	50	47	46	44	5	4	45	44	42	40	5	3	46	44	42	41	5	3	48	46	44	43	5	4	48	46	44	42	5	3	Band 2
55	53	51	49	7	6	56	53	51	49	7	6	57	54	52	51	7	6	54	52	51	49	7	7	54	52	51	49	8	6	54	52	51	49	7	6	Band 3
54	51	48	45	5	5	53	49	46	44	5	5	55	51	48	45	5	5	52	48	46	42	5	5	47	44	41	38	4	4	48	45	42	40	4	4	Band 4
CAL WEDGE (LOW GAIN, COMPRESSED, LAMP A)																																				
52	50	48	47	5	4	51	49	48	46	4	4	54	51	50	48	5	6	52	51	50	48	5	4	46	45	43	42	4	4	50	48	47	45	4	4	Band 1
51	49	47	46	5	4	55	53	51	49	5	5	51	49	48	46	5	5	51	49	47	46	5	5	53	51	50	48	5	5	54	52	50	49	5	5	Band 2
55	53	51	49	7	6	55	53	51	49	7	6	57	54	52	51	7	6	54	52	51	49	7	7	54	52	51	49	8	6	54	52	51	49	7	6	Band 3
54	51	48	45	5	5	53	49	46	44	5	5	55	51	48	45	5	5	52	48	46	42	5	5	47	44	41	38	4	4	48	45	42	40	4	4	Band 4
CAL WEDGE (HIGH GAIN, LINEAR, LAMP B)																																				
46	43	41	39	3	2	46	43	41	39	3	2	47	45	43	41	3	2	46	44	42	39	3	2	45	43	41	39	3	2	47	44	42	40	3	2	Band 1
44	41	40	38	4	4	47	44	42	40	4	4	39	37	36	34	4	3	42	40	38	36	4	4	44	42	40	38	4	4	46	43	41	39	4	4	Band 2
45	42	40	38	3	3	45	42	40	38	3	3	47	45	42	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	39	3	2	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (LOW GAIN, LINEAR, LAMP B)																																				
51	48	46	44	2	2	51	48	46	43	2	2	53	50	47	45	2	2	52	49	47	45	2	2	50	48	45	43	2	2	52	49	47	45	2	2	Band 1
50	47	45	42	2	2	53	51	48	45	3	2	46	43	41	39	2	2	48	46	43	40	2	2	51	49	46	43	3	2	53	50	47	45	3	2	Band 2
45	42	40	38	3	3	45	42	40	38	3	3	47	45	42	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	39	3	2	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (HIGH GAIN, COMPRESSED, LAMP B)																																				
51	50	48	47	6	6	51	50	48	47	7	6	53	51	50	48	7	6	52	50	49	47	7	6	51	50	48	47	6	6	52	51	49	47	7	6	Band 1
51	49	47	46	9	9	52	51	49	48	9	9	47	46	45	43	8	8	49	48	46	45	9	9	51	49	48	46	10	9	52	50	48	47	10	9	Band 2
51	49	48	46	7	6	51	49	48	46	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	47	46	6	5	52	50	48	47	6	6	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	38	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (LOW GAIN, COMPRESSED, LAMP B)																																				
55	53	52	50	5	5	55	53	51	50	5	5	57	55	53	51	6	2	56	54	52	51	5	2	55	53	51	50	5	5	56	54	52	51	6	5	Band 1
55	53	51	49	5	5	57	55	53	51	6	5	52	50	49	47	5	5	53	52	50	48	6	5	55	54	52	50	7	6	56	55	53	51	7	6	Band 2
51	49	48	46	7	6	51	49	48	46	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	47	46	6	5	52	50	48	47	6	6	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4

Table B-4a
Landsat-5 Nominal Calibration Record

1st DETECTOR OF BAND						2nd DETECTOR OF BAND						3rd DETECTOR OF BAND						4th DETECTOR OF BAND						5th DETECTOR OF BAND						6th DETECTOR OF BAND						
1st WORD COUNT					LAST WORD COUNT	1st WORD COUNT					LAST WORD COUNT	1st WORD COUNT					LAST WORD COUNT	1st WORD COUNT					LAST WORD COUNT	1st WORD COUNT					LAST WORD COUNT	1st WORD COUNT					LAST WORD COUNT	
ACTIVE DETECTOR STATUS: AAAAAAAAAAAAAAAAAAAAAAAA																																				
CAL WEDGE (HIGH GAIN, LINEAR, LAMP A)																																				
48	45	43	41	3	3	48	45	43	41	3	3	49	46	44	42	3	3	45	43	41	39	3	3	48	48	43	41	3	3	47	44	43	40	3	3	BAND 1
50	48	46	44	6	6	50	48	45	43	6	5	51	48	46	44	6	5	52	50	48	45	6	5	52	50	48	45	6	5	53	51	48	46	6	5	BAND 2
45	42	40	38	3	3	48	45	42	40	3	3	48	45	43	40	3	3	50	47	44	42	4	3	50	47	44	42	4	3	48	45	43	40	3	3	BAND 3
48	45	43	40	5	5	54	51	48	45	6	6	50	47	44	42	5	5	53	50	47	44	6	5	54	51	48	45	6	6	52	48	46	43	6	5	BAND 4
CAL WEDGE (LOW GAIN, LINEAR, LAMP A)																																				
51	48	46	43	3	3	51	48	46	43	3	3	52	49	47	45	3	3	48	46	44	41	3	3	51	49	47	44	3	3	50	48	45	43	3	3	BAND 1
52	50	47	45	3	2	52	49	47	45	3	2	53	50	48	46	3	2	53	51	48	46	3	2	54	51	49	46	3	2	54	51	49	46	3	2	BAND 2
45	42	40	38	3	3	48	45	42	40	3	3	48	45	43	40	3	3	50	47	44	42	4	3	50	47	44	42	4	3	48	45	43	40	3	3	BAND 3
48	46	43	40	5	5	54	51	48	45	6	6	50	47	44	42	5	5	53	50	47	44	6	5	54	51	48	45	6	6	52	48	46	43	6	5	BAND 4
CAL WEDGE (HIGH GAIN, COMPRESSED, LAMP A)																																				
53	51	50	48	8	7	53	51	50	48	8	7	54	52	51	49	8	7	51	50	49	47	8	7	53	52	50	48	8	7	53	51	50	48	8	7	BAND 1
55	53	52	50	13	12	54	53	51	50	13	12	55	53	52	50	13	12	56	54	53	51	13	12	56	54	53	51	14	12	57	55	53	52	14	12	BAND 2
51	49	48	46	8	7	53	51	49	48	8	7	53	51	50	48	8	7	54	53	50	49	9	8	54	53	51	49	9	8	53	51	50	48	8	7	BAND 3
48	45	43	40	5	5	54	51	48	45	6	6	50	47	44	42	5	5	53	50	47	44	6	5	54	51	48	45	6	6	52	48	46	43	6	5	BAND 4
CAL WEDGE (LOW GAIN, COMPRESSED, LAMP A)																																				
55	54	52	50	7	7	55	53	52	50	7	7	56	54	53	51	7	7	53	52	50	49	7	7	55	54	52	51	7	7	54	53	51	50	7	7	BAND 1
56	54	53	51	7	6	56	54	52	51	7	6	56	55	53	52	7	6	57	55	53	52	7	6	57	55	54	52	7	6	57	56	54	52	7	6	BAND 2
51	49	48	46	8	7	53	51	49	48	8	7	53	51	50	48	8	7	54	53	50	49	9	8	54	53	51	49	9	8	53	51	50	48	8	7	BAND 3
48	45	43	40	5	5	54	51	48	45	6	6	50	47	44	42	5	5	53	50	47	44	6	5	54	51	48	45	6	6	52	48	46	43	6	5	BAND 4
CAL WEDGE (HIGH GAIN, LINEAR, LAMP B)																																				
43	41	39	37	4	4	43	41	39	37	4	4	39	37	36	34	4	4	36	35	33	31	3	3	38	36	35	33	3	3	38	36	34	33	3	3	BAND 1
47	44	42	40	7	7	44	41	39	38	6	6	42	40	38	37	6	6	42	40	39	37	6	6	41	39	38	36	6	6	43	40	39	37	6	6	BAND 2
40	37	36	34	3	3	41	39	37	35	3	3	40	37	36	34	3	3	39	37	36	34	3	3	41	38	36	35	3	3	40	38	36	35	3	3	BAND 3
36	34	31	30	4	4	40	38	36	34	5	4	37	34	32	30	4	4	39	37	35	33	4	4	40	38	36	34	5	4	36	34	32	30	4	4	BAND 4
CAL WEDGE (LOW GAIN, LINEAR, LAMP B)																																				
45	43	41	39	3	2	43	41	39	37	3	3	42	41	39	37	2	2	38	37	36	34	2	2	42	39	37	36	2	2	42	39	38	36	2	2	BAND 1
48	46	44	42	3	2	45	44	41	39	2	2	44	42	40	38	2	2	44	42	40	38	2	2	43	41	39	38	2	2	44	42	40	38	2	2	BAND 2
40	37	36	34	3	3	41	39	37	35	3	3	40	37	36	34	3	3	39	37	36	34	3	3	41	38	36	35	3	3	40	38	36	35	3	3	BAND 3
36	34	31	30	4	4	40	38	36	34	5	4	37	34	32	30	4	4	39	37	35	33	4	4	40	38	36	34	5	4	36	34	32	30	4	4	BAND 4
CAL WEDGE (HIGH GAIN, COMPRESSED, LAMP B)																																				
50	48	47	46	9	9	50	48	47	46	9	9	47	46	45	43	9	9	45	44	43	42	8	8	47	45	44	43	8	8	47	45	44	43	8	8	BAND 1
52	51	49	48	14	14	50	49	47	47	14	14	49	48	47	46	14	14	49	48	47	46	14	14	49	47	46	45	14	14	50	48	47	46	14	14	BAND 2
48	46	45	43	5	5	48	47	46	44	7	7	48	46	45	44	7	7	47	46	45	43	7	7	48	47	45	44	7	7	48	47	45	44	7	7	BAND 3
36	34	31	30	4	4	40	38	36	34	5	4	37	34	32	30	4	4	39	37	35	33	4	4	40	38	36	34	5	4	36	34	32	30	4	4	BAND 4
CAL WEDGE (LOW GAIN, COMPRESSED, LAMP B)																																				
51	50	49	47	7	6	50	48	47	46	6	6	49	48	47	46	6	6	47	46	45	43	6	6	48	47	47	45	6	6	49	47	47	45	6	6	BAND 1
53	52	51	49	7	6	51	50	49	47	6	6	50	49	48	47	6	6	50	49	48	47	6	6	50	49	47	46	6	6	51	49	48	47	2	2	BAND 2
48	46	45	43	5	5	48	47	46	44	7	7	48	46	45	44	7	7	47	46	45	43	7	7	48	47	45	44	7	7	48	47	45	44	7	7	BAND 3
36	34	31	30	4	4	40	38	36	34	5	4	37	34	32	30	4	4	39	37	35	33	4	4	40	38	36	34	5	4	36	34	32	30	4	4	BAND 4

Table B-5
Landsat-4 Lamp A (Prime)-High Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

			FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR	1	OFFSETS:	-0.6034660E-01	-0.2014560E-01	0.9569900E-02	0.3634670E-01	0.5090237	0.5155502	BAND 1
		GAINS:	0.4393915	0.3782430	0.3180776	0.2638616	-0.6931777	-0.7063921	
DETECTOR	2	OFFSETS:	-0.4696410E-01	-0.1757830E-01	0.1402540E-01	0.3933630E-01	0.5018356	0.5093431	
		GAINS:	0.4459089	0.3845716	0.3186063	0.2657746	-0.6995937	-0.7152642	
DETECTOR	3	OFFSETS:	-0.4951040E-01	-0.2031000E-01	0.9761000E-02	0.3898490E-01	0.5069316	0.5141420	
		GAINS:	0.4415793	0.3819324	0.3205073	0.2608126	-0.6950506	-0.7097797	
DETECTOR	4	OFFSETS:	-0.4863200E-01	-0.1837630E-01	0.1167500E-01	0.3824920E-01	0.5049975	0.5120857	
		GAINS:	0.4504787	0.3871738	0.3242962	0.2686936	-0.7079045	-0.7227359	
DETECTOR	5	OFFSETS:	-0.4772620E-01	-0.1728000E-01	0.1305800E-01	0.3843440E-01	0.5031191	0.5103938	
		GAINS:	0.4419056	0.3791494	0.3166170	0.2643114	-0.6934940	-0.7084886	
DETECTOR	6	OFFSETS:	-0.4818700E-01	-0.1804520E-01	0.1234110E-01	0.3968050E-01	0.5031267	0.5110831	
		GAINS:	0.4475009	0.3847212	0.3214320	0.2644894	-0.7007846	-0.7173566	
DETECTOR	7	OFFSETS:	-0.4978410E-01	-0.1379920E-01	0.2319780E-01	0.5015760E-01	0.4914715	0.4987552	BAND 2
		GAINS:	0.4471673	0.3728172	0.2963865	0.2406913	-0.6710020	-0.6860487	
DETECTOR	8	OFFSETS:	-0.4786690E-01	-0.5499200E-02	0.2722290C-01	0.4969290E-01	0.4850060	0.4914417	
		GAINS:	0.4527151	0.3633089	0.2942579	0.2468412	-0.6717733	-0.6853501	
DETECTOR	9	OFFSETS:	-0.4764340E-01	-0.6085000E-02	0.3098510E-01	0.5721700E-01	0.4803672	0.4851587	
		GAINS:	0.4620484	0.3724492	0.2926267	0.2359710	-0.6763325	-0.6866624	
DETECTOR	10	OFFSETS:	-0.4595430E-01	-0.1156960E-01	0.2572820E-01	0.5119340E-01	0.4871623	0.4934390	
		GAINS:	0.4537220	0.3803466	0.3007549	0.2484138	-0.6839200	-0.6973141	
DETECTOR	11	OFFSETS:	-0.4826260E-01	-0.1290520E-01	0.2150040E-01	0.4753510E-01	0.4926770	0.4994534	
		GAINS:	0.4394034	0.3671185	0.2967794	0.2435538	-0.6664988	-0.6803529	
DETECTOR	12	OFFSETS:	-0.4813180E-01	-0.9684100E-02	0.2116110E-01	0.4747740E-01	0.4910113	0.4981661	
		GAINS:	0.4532148	0.3720921	0.3070097	0.2514838	-0.6843521	-0.6994466	
DETECTOR	13	OFFSETS:	-0.6704220E-01	-0.2197540E-01	0.8423000E-02	0.3960200E-01	0.5132497	0.5177433	BAND 3
		GAINS:	0.4055327	0.3419647	0.2868595	0.2303389	-0.8282750	-0.6364208	
DETECTOR	14	OFFSETS:	-0.5796830E-01	-0.2231510E-01	0.8275200E-02	0.3914950E-01	0.5141711	0.5186867	
		GAINS:	0.4074623	0.3427829	0.2872969	0.2312958	-0.6303183	-0.6385089	
DETECTOR	15	OFFSETS:	-0.5926110E-01	-0.2706710E-01	0.4116500E-02	0.3753270E-01	0.5200683	0.5246107	
		GAINS:	0.4143347	0.3552930	0.2981066	0.2368220	-0.6481126	-0.6564431	
DETECTOR	16	OFFSETS:	-0.6022840E-01	-0.2476510E-01	0.7526200E-02	0.3828340E-01	0.5173103	0.5218927	
		GAINS:	0.4272965	0.3605108	0.2996986	0.2418133	-0.6603447	-0.6689745	
DETECTOR	17	OFFSETS:	-0.5873130E-01	-0.2233320E-01	0.8034400E-02	0.3840870E-01	0.5149243	0.5196952	
		GAINS:	0.4306794	0.3611317	0.3031066	0.2450689	-0.6654352	-0.6745509	
DETECTOR	18	OFFSETS:	-0.5866450E-01	-0.2347670E-01	0.8840600E-02	0.3874310E-01	0.5149391	0.5196176	
		GAINS:	0.4225129	0.3565332	0.2959356	0.2398664	-0.6530377	-0.6618102	
DETECTOR	19	OFFSETS:	-0.8950200E-01	-0.4144460E-01	-0.3951700E-02	0.3990730E-01	0.5467716	0.5482212	BAND 4
		GAINS:	0.4161379	0.3380703	0.2771646	0.2059172	-0.6174682	-0.6198230	
DETECTOR	20	OFFSETS:	-0.8913090E-01	-0.4259440E-01	-0.2070100E-02	0.3881090E-01	0.5463896	0.5485971	
		GAINS:	0.4322807	0.3536371	0.2851537	0.2160676	-0.6417043	-0.6454350	
DETECTOR	21	OFFSETS:	-0.8683630E-01	-0.3995820E-01	-0.1126500E-02	0.3891670E-01	0.5437302	0.5452751	
		GAINS:	0.4192705	0.3417387	0.2776146	0.2112885	-0.6236283	-0.6261835	
DETECTOR	22	OFFSETS:	-0.8828550E-01	-0.4554920E-01	-0.2763300E-02	0.4064930E-01	0.5471393	0.5488122	
		GAINS:	0.4478498	0.3727786	0.2970214	0.2213627	-0.6683377	-0.6712764	
DETECTOR	23	OFFSETS:	-0.8513990E-01	-0.4298810E-01	-0.7428000E-03	0.3921280E-01	0.5441099	0.5455478	
		GAINS:	0.4754781	0.3958642	0.3161137	0.2406665	-0.7127149	-0.7154302	
DETECTOR	24	OFFSETS:	-0.8418970E-01	-0.4236670E-01	-0.3246000E-03	0.3645530E-01	0.5442715	0.5461547	
		GAINS:	0.4599492	0.3832669	0.3061812	0.2387447	-0.6923453	-0.6957984	

Table B-5a
Landsat-5 Lamp A (Prime)-High Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

			FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR	1	OFFSETS:	-0.5150710E-01	-0.2337910E-01	0.5782100E-02	0.3779060E-01	0.5133362	0.6179753	BAND 1
		GAINS:	0.3946434	0.3437642	0.2910157	0.2331176	-0.6270734	-0.6354649	
DETECTOR	2	OFFSETS:	-0.5505300E-01	-0.2622700E-01	0.4088200E-02	0.3520800E-01	0.5185983	0.5233855	
		GAINS:	0.3785812	0.3293617	0.2775989	0.2244630	-0.6009150	-0.6090890	
DETECTOR	3	OFFSETS:	-0.5425250E-01	-0.2595450E-01	0.3668500E-02	0.3405830E-01	0.5188444	0.5236351	
		GAINS:	0.3912447	0.3411294	0.2886674	0.2348477	-0.6237017	-0.6321862	
DETECTOR	4	OFFSETS:	-0.5230800E-01	-0.2408040E-01	0.5934000E-02	0.3552010E-01	0.5148853	0.5200477	
		GAINS:	0.4008732	0.3491973	0.2942508	0.2400879	-0.6374786	-0.6469293	
DETECTOR	5	OFFSETS:	-0.5050420E-01	-0.2307180E-01	0.6425400E-02	0.3628040E-01	0.5126587	0.5182102	
		GAINS:	0.3878836	0.3388869	0.2862024	0.2328795	-0.6179676	-0.6278833	
DETECTOR	6	OFFSETS:	-0.5332530E-01	-0.2504630E-01	0.4845500E-02	0.3636370E-01	0.5167888	0.5213726	
		GAINS:	0.4005982	0.3491031	0.2946711	0.2372776	-0.6357406	-0.6459080	
DETECTOR	7	OFFSETS:	-0.7018360E-01	-0.3864890E-01	-0.8170500E-02	0.2295900E-01	0.5437284	0.5503135	BAND 2
		GAINS:	0.3764782	0.3263531	0.2779068	0.2284255	-0.5993463	-0.6098132	
DETECTOR	8	OFFSETS:	-0.7151260E-01	-0.4003360E-01	-0.7376100E-02	0.2446060E-01	0.5433122	0.5511491	
		GAINS:	0.3704422	0.3214825	0.2706899	0.2211745	-0.5857995	-0.5979883	
DETECTOR	9	OFFSETS:	-0.6900070E-01	-0.3853400E-01	-0.7649600E-02	0.2286900E-01	0.5420689	0.5502455	
		GAINS:	0.3607839	0.3141423	0.2668616	0.2201405	-0.5747042	-0.5872216	
DETECTOR	10	OFFSETS:	-0.6750680E-01	-0.3869920E-01	-0.8210400E-02	0.2285480E-01	0.5413868	0.5501743	
		GAINS:	0.3521439	0.3088242	0.2629759	0.2162611	-0.5634947	-0.5767094	
DETECTOR	11	OFFSETS:	-0.6995200E-01	-0.3954710E-01	-0.9176400E-02	0.2187600E-01	0.5440727	0.5527259	
		GAINS:	0.3722317	0.3244010	0.2766241	0.2277748	-0.5937088	-0.6073208	
DETECTOR	12	OFFSETS:	-0.6788250E-01	-0.3768370E-01	-0.8015700E-02	0.2292980E-01	0.5409926	0.5496593	
		GAINS:	0.3670806	0.3198182	0.2733860	0.2249554	-0.5858371	-0.5994016	
DETECTOR	13	OFFSETS:	-0.6138200E-01	-0.2705220E-01	0.1010480E-01	0.3597950E-01	0.5179476	0.5244017	BAND 3
		GAINS:	0.3900888	0.3313658	0.2678068	0.2236469	-0.6008841	-0.6119242	
DETECTOR	14	OFFSETS:	-0.6226270E-01	-0.2719210E-01	0.9707100E-02	0.3794290E-01	0.5177627	0.5240430	
		GAINS:	0.3837222	0.3249382	0.2630894	0.2157615	-0.5884924	-0.5990189	
DETECTOR	15	OFFSETS:	-0.6083520E-01	-0.2774190E-01	0.7409500E-02	0.3870720E-01	0.5179865	0.5244730	
		GAINS:	0.3764717	0.3217087	0.2635399	0.2117482	-0.5813673	-0.5921011	
DETECTOR	16	OFFSETS:	0.6061800E-01	-0.2861120E-01	0.8275700E-02	0.3767610E-01	0.5182114	0.5250673	
		GAINS:	0.3763611	0.3233610	0.2622799	0.2135975	-0.5821233	0.5934759	
DETECTOR	17	OFFSETS:	-0.6113430E-01	-0.2853360E-01	0.7597700E-02	0.3780760E-01	0.5186779	0.5255855	
		GAINS:	0.3762018	0.3223634	0.2626945	0.2128044	-0.5813282	-0.5927356	
DETECTOR	18	OFFSETS:	-0.6088770E-01	-0.2898700E-01	0.7551500E-02	0.3845260E-01	0.5183784	0.5254911	
		GAINS:	0.3863155	0.3321580	0.2701273	0.2176670	-0.5970963	-0.6091715	
DETECTOR	19	OFFSETS:	-0.8868130E 01	-0.4675300E-01	-0.8292200E-02	0.3091720E-01	0.5549851	0.5578250	BAND 4
		GAINS:	0.4185761	0.3498454	0.2867994	0.2225253	-0.6365463	-0.6412016	
DETECTOR	20	OFFSETS:	-0.9096650E-01	-0.4801160E-01	-0.7266400E-02	0.2918870E-01	0.5567080	0.5603476	
		GAINS:	0.3749706	0.3124521	0.2531499	0.2000912	-0.5676837	-0.5729810	
DETECTOR	21	OFFSETS:	-0.8865510E-01	-0.4568640E-01	-0.5057800E-02	0.2894180E-01	0.5524995	0.5579589	
		GAINS:	0.4022836	0.3345820	0.2705677	0.2169988	-0.6079159	-0.6165177	
DETECTOR	22	OFFSETS:	-0.8907060E-01	-0.4671130E-01	-0.7193100E-02	0.2935220E-01	0.5533396	0.5602846	
		GAINS:	0.3725689	0.3108578	0.2532864	0.2000453	-0.5633211	-0.5734386	
DETECTOR	23	OFFSETS:	-0.9340950E-01	-0.4880080E-01	-0.6520000E-02	0.2714800E-01	0.5595728	0.5620105	
		GAINS:	0.3837239	0.3179070	0.2555247	0.2058500	-0.5797049	-0.5833015	
DETECTOR	24	OFFSETS:	-0.9021130E-01	-0.4461990E-01	-0.9269300E-02	0.2864670E-01	0.5533698	0.5620862	
		GAINS:	0.3909811	0.3215886	0.2677833	0.2100738	-0.5885805	-0.6018477	

Table B-6

Landsat-4 Lamp A (Prime)-Low Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

			FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR	1	OFFSETS:	-0.5044050E-01	-0.2074160E-01	0.8467600E-02	0.3403190E-01	0.5137314	0.5149615	
		GAINS:	0.4066399	0.3510138	0.2963050	0.2484233	-0.6500483	-0.6523336	
DETECTOR	2	OFFSETS:	-0.4896130E-01	-0.1938700E-01	0.7744700E-02	0.3452540E-01	0.5123792	0.5136988	
		GAINS	0.4174407	0.3601867	0.3076617	0.2558161	-0.6692752	-0.6718299	
DETECTOR	3	OFFSETS:	-0.4889510E-01	-0.1909270E-01	0.7016700E-02	0.3240320E-01	0.5135559	0.5150127	
		GAINS:	0.4083158	0.3518636	0.3024074	0.2543204	-0.6570740	-0.6598334	
DETECTOR	4	OFFSETS:	-0.4896040E-01	-0.1941010E-01	0.7305400E-02	0.3306160E-01	0.5131428	0.5148601	Band 1
		GAINS:	0.4205451	0.3629122	0.3108079	0.2605745	-0.6757452	-0.6790944	
DETECTOR	5	OFFSETS:	-0.4955080E-01	-0.2222870E-01	0.9532700E-02	0.3481040E-01	0.5126960	0.5147414	
		GAINS:	0.4177801	0.3649877	0.3036175	0.2547755	-0.6686032	-0.6725572	
DETECTOR	6	OFFSETS:	-0.4973960E-01	-0.1888300E-01	0.7961100E-02	0.3248670E-01	0.5132293	0.5149455	
		GAINS:	0.4202252	0.3603066	0.3081800	0.2605552	-0.6729670	-0.6762997	
DETECTOR	7	OFFSETS:	-0.5544900E-01	-0.1940160E-01	0.1182860E-01	0.4251390E-01	0.5086271	0.5118808	
		GAINS:	0.3761566	0.3151097	0.2622208	0.2102647	-0.5791156	-0.5846258	
DETECTOR	8	OFFSETS:	-0.5443910E-01	-0.1916970E-01	0.1063320E-01	0.3967680E-01	0.5098675	0.5134305	
		GAINS:	0.3768380	0.3167271	0.2659329	0.2164330	-0.5849292	-0.5910016	
DETECTOR	9	OFFSETS:	-0.5335200E-01	-0.1817020E-01	0.1165940E-01	0.3866120E-01	0.5090845	0.5121167	
		GAINS:	0.3771513	0.3168435	0.2657101	0.2194242	-0.5869656	-0.5921633	Band 2
DETECTOR	10	OFFSETS:	-0.5441640E-01	-0.1823660E-01	0.1291340E-01	0.4082070E-01	0.5080326	0.5108856	
		GAINS:	0.3847621	0.3217964	0.2675844	0.2190160	-0.5940966	-0.5990620	
DETECTOR	11	OFFSETS:	-0.5380060E-01	-0.1977140E-01	0.1027140E-01	0.4065980E-01	0.5094633	0.5129768	
		GAINS:	0.3696881	0.3126266	0.2622496	-0.2109577	-0.5748152	-0.5807067	
DETECTOR	12	OFFSETS:	-0.5412580E-01	-0.1990290E-01	0.9926100E-02	0.4152150E-01	0.5094231	0.5131574	
		GAINS:	0.3807511	0.3217345	0.2702951	0.2158096	-0.5910753	-0.5975148	
DETECTOR	13	OFFSETS:	-0.5704220E-01	-0.2197540E-01	0.8423000E-02	0.3960200E-01	0.5132497	0.5177433	
		GAINS:	0.4055327	0.3419647	0.2868595	0.2303389	-0.6282750	-0.6364208	
DETECTOR	14	OFFSETS:	-0.5796830E-01	-0.2231510E-01	0.8275200E-02	0.3914960E-01	0.5141711	0.5186867	
		GAINS:	0.4074523	0.3427829	0.2872969	0.2312958	-0.6303183	-0.6385089	
DETECTOR	15	OFFSETS:	-0.5926110E-01	-0.2706710E-01	0.4115500E-02	0.3753270E-01	0.5200683	0.5246107	
		GAINS:	0.4143347	0.3552930	0.2981066	0.2368220	-0.6481126	-0.6564431	Band 3
DETECTOR	16	OFFSETS:	-0.6022840E-01	-0.2476510E-01	0.7526200E-02	0.3826340E-01	0.5173103	0.5218927	
		GAINS:	0.4272965	0.3605108	0.2996986	0.2418133	-0.6603447	-0.6689745	
DETECTOR	17	OFFSETS:	-0.5873130E-01	-0.2233320E-01	0.8034400E-02	0.3840870E-01	0.5149243	0.5196952	
		GAINS:	0.4306794	0.3611317	0.3031066	0.2450689	-0.6654352	-0.6745509	
DETECTOR	18	OFFSETS:	-0.5866450E-01	-0.2347670E-01	0.8840600E-02	0.3874310E-01	0.5149391	0.5196175	
		GAINS:	0.4225129	0.3565332	0.2959356	0.2398664	-0.6530377	-0.6618102	
DETECTOR	19	OFFSETS:	-0.8950200E-01	-0.4144460E-01	-0.3951700E-02	0.3990730E-01	0.5467716	0.5482212	
		GAINS:	0.4161379	0.3380703	0.2771646	0.2059172	-0.6174682	-0.6198230	
DETECTOR	20	OFFSETS:	-0.8913090E-01	-0.4259440E-01	-0.2070100E-02	0.3881090E-01	0.5463896	0.5485971	
		GAINS:	0.4322807	0.3536371	0.2851537	0.2160676	-0.6417043	-0.6454350	
DETECTOR	21	OFFSETS:	-0.8683630E-01	-0.3996820E-01	-0.1126500E-02	0.3891670E-01	0.5437302	0.5452751	
		GAINS:	0.4192706	0.3417387	0.2775145	0.2112865	-0.6236283	-0.6261835	
DETECTOR	22	OFFSETS:	-0.8828550E-01	-0.4554920E-01	-0.2763300E-02	0.4064930E-01	0.5471393	0.5488122	Band 4
		GAINS:	0.4478498	0.3727786	0.2976214	0.2213627	-0.6683377	-0.6712764	
DETECTOR	23	OFFSETS:	-0.8513990E-01	-0.4298810E-01	-0.7428000E-03	0.3921280E-01	0.5441099	0.5455478	
		GAINS:	0.4754781	0.3958842	0.3161137	0.2406665	-0.7127149	-0.7154302	
DETECTOR	24	OFFSETS:	-0.8418970E-01	-0.4236670E-01	-0.3246000E-03	0.3645530E-01	0.5442715	0.5461547	
		GAINS:	0.4599492	0.3832669	0.3061812	0.2387447	-0.6923453	-0.6957984	

Table B-6a

Landsat-5 Lamp A (Prime)-Low Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

		FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR 1	OFFSETS:	-0.4966370E-01	-0.2412860E-01	0.4678900E-02	0.3173720E-01	0.5182710	0.5191056	
	GAINS:	0.3625953	0.3197954	0.2715108	0.2261680	-0.5893304	-0.5907292	
DETECTOR 2	OFFSETS:	-0.5229570E-01	-0.2355920E-01	0.3284100E-02	0.3272390E-01	0.5187814	0.5210659	
	GAINS:	0.3492906	0.3034502	0.2606292	0.2136667	-0.5616962	-0.5653405	
DETECTOR 3	OFFSETS:	-0.4969280E-01	-0.2371420E-01	0.3035900E-02	0.3152260E-01	0.5182973	0.5205511	
	GAINS:	0.3575859	0.3146500	0.2704395	0.2233580	-0.5811539	-0.5848793	
DETECTOR 4	OFFSETS:	-0.5282810E-01	-0.2430230E-01	0.3325300E-02	0.3294590E-01	0.5197349	0.5211250	BAND 1
	GAINS:	0.3768077	0.3278372	0.2804087	0.2295593	-0.6061131	-0.6084997	
DETECTOR 5	OFFSETS:	-0.4928130E-01	-0.2461240E-01	0.3318700E-02	0.3161160E-01	0.5187069	0.5202559	
	GAINS:	0.3634229	0.3219064	0.2749007	0.2272864	-0.5924545	-0.5950618	
DETECTOR 6	OFFSETS:	-0.5209600E-01	-0.2453340E-01	0.2812700E-02	0.3156880E-01	0.5201258	0.5221230	
	GAINS:	0.3742019	0.3270553	0.2802787	0.2310905	-0.6046052	-0.6080214	
DETECTOR 7	OFFSETS:	-0.5058490E-01	-0.2060650E-01	0.6197400E-02	0.3417580E-01	0.5127867	0.5180310	
	GAINS:	0.3261521	0.2811467	0.2409068	0.1989039	-0.5196180	-0.5274912	
DETECTOR 8	OFFSETS:	-0.4975610E-01	-0.2163970E-01	0.6670300E-02	0.3403870E-01	0.5127270	0.5179598	
	GAINS:	0.3180973	0.2767720	0.2351621	0.1949360	-0.5086381	-0.5163292	
DETECTOR 9	OFFSETS:	-0.5032760E-01	-0.2134400E-01	0.6061900E-02	0.3413120E-01	0.5131772	0.5183008	
	GAINS:	0.3142368	0.2722645	0.2325772	0.1919290	-0.5017939	-0.5092136	
DETECTOR 10	OFFSETS:	-0.5135700E-01	-0.2057880E-01	0.5490600E-02	0.3296050E-01	0.5140550	0.5194294	BAND 2
	GAINS:	0.3123491	0.2682550	0.2309070	0.1915525	-0.4976819	-0.5053816	
DETECTOR 11	OFFSETS:	-0.5066470E-01	-0.2040370E-01	0.5205600E-02	0.3295270E-01	0.5139646	0.5189445	
	GAINS:	0.3252072	0.2799256	0.2416047	0.2000849	-0.5196853	-0.5271370	
DETECTOR 12	OFFSETS:	-0.4999190E-01	-0.1895890E-01	0.5871200E-02	0.3399420E-01	0.5116467	0.5174387	
	GAINS:	0.3214461	0.2754039	0.2385647	0.1968398	-0.5118304	-0.5204237	
DETECTOR 13	OFFSETS:	-0.6138200E-01	-0.2705220E-01	0.1010480E-01	0.3597950E-01	0.5179475	0.5244017	
	GAINS:	0.3900888	0.3313658	0.2678068	0.2235469	-0.6008841	-0.6119242	
DETECTOR 14	OFFSETS:	-0.6226270E-01	-0.2719210E-01	0.9707100E-02	0.3794290E-01	0.5177627	0.5240430	
	GAINS:	0.3837222	0.3249382	0.2630894	0.2157615	-0.5884924	-0.5990189	
DETECTOR 15	OFFSETS:	-0.6083520E-01	-0.2774190E-01	0.7409500E-02	0.3870720E-01	0.5179865	0.5244730	
	GAINS:	0.3764717	0.3217087	0.2635399	0.2117482	-0.5813673	-0.5921011	
DETECTOR 16	OFFSETS:	-0.6061800E-01	-0.2861120E-01	0.8275700E-02	0.3767610E-01	0.5182114	0.5250673	BAND 3
	GAINS:	0.3763611	0.3233610	0.2622799	0.2135975	-0.5821233	-0.5934759	
DETECTOR 17	OFFSETS:	-0.6113430E-01	-0.2853360E-01	0.7597700E-02	0.3780760E-01	0.5186779	0.5255855	
	GAINS:	0.3762018	0.3223634	0.2626945	0.2128044	-0.5813282	-0.5927356	
DETECTOR 18	OFFSETS:	-0.6088770E-01	-0.2898700E-01	0.7551500E-02	0.3845260E-01	0.5183784	0.5254911	
	GAINS:	0.3863155	0.3321580	0.2701273	0.2176670	-0.5970963	-0.6091715	
DETECTOR 19	OFFSETS:	-0.8868130E-01	-0.4675300E-01	-0.8292200E-02	0.3091720E-01	0.5549851	0.5578250	
	GAINS:	0.4185761	0.3498454	0.2867994	0.2225253	-0.6365463	-0.6412016	
DETECTOR 20	OFFSETS:	-0.9096650E-01	-0.4801160E-01	-0.7266400E-02	0.2918870E-01	0.5567080	0.5603476	
	GAINS:	0.3749706	0.3124521	0.2531499	0.2000912	-0.5676837	-0.5729810	
DETECTOR 21	OFFSETS:	-0.8865510E-01	-0.4568640E-01	-0.5057800E-02	0.2894180E-01	0.5524995	0.5579589	
	GAINS:	0.4022836	0.3345820	0.2705677	0.2169988	-0.6079159	-0.6165177	
DETECTOR 22	OFFSETS:	-0.8907060E-01	-0.4671130E-01	-0.7193100E-02	0.2935220E-01	0.5533396	0.5602846	BAND 4
	GAINS:	0.3725689	0.3108578	0.2532864	0.2000453	-0.5633211	-0.5734386	
DETECTOR 23	OFFSETS:	-0.9340950E-01	-0.4880080E-01	-0.6520000E-02	0.2714800E-01	0.5595728	0.5620105	
	GAINS:	0.3837239	0.3179070	0.2555247	0.2058500	-0.5797049	-0.5833015	
DETECTOR 24	OFFSETS:	-0.9021130E-01	-0.4461990E-01	0.9269300E-02	0.2864670E-01	0.5533698	0.5620862	
	GAINS:	0.3909811	0.3215886	0.2677833	0.2100738	-0.5885805	-0.6018477	

Table B-7
Landsat-4 Lamp B (Redundant) - High Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

			FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR	1	OFFSETS:	-0.5383770E-01	-0.2314010E-01	0.6896000E-02	0.3447840E-01	0.5152770	0.5203248	
		GAINS:	0.4306146	0.3706659	0.3120100	0.2581465	-0.6807873	-0.6906456	
DETECTOR	2	OFFSETS:	-0.5131310E-01	-0.2134540E-01	0.8583100E-02	0.3678250E-01	0.5111665	0.5161244	
		GAINS:	0.4441122	0.3830557	0.3220798	0.2646262	-0.7018843	-0.7119856	
DETECTOR	3	OFFSETS:	-0.5204000E-01	-0.2547210E-01	0.4418200E-02	0.3538790E-01	0.5161735	0.5215313	
		GAINS:	0.4359769	0.3830154	0.3234310	0.2618950	-0.8967177	-0.7073981	BAND 1
DETECTOR	4	OFFSETS:	-0.5517190E-01	-0.2453140E-01	0.5966900E-02	0.3561150E-01	0.5164109	0.5217128	
		GAINS:	0.4524348	0.3899441	0.3277441	0.2672845	-0.7132953	-0.7241084	
DETECTOR	5	OFFSETS:	-0.5234010E-01	-0.2212130E-01	0.9521300E-02	0.3583130E-01	0.5118428	0.5172654	
		GAINS:	0.4387688	0.3782274	0.3148327	0.2621216	-0.6916425	-0.7024066	
DETECTOR	6	OFFSETS:	-0.5273780E-01	-0.2346360E-01	0.6308200E-02	0.3697190E-01	0.5138791	0.5190389	
		GAINS:	0.4451463	0.3857524	0.3253493	0.2631319	-0.7044545	-0.7149233	
DETECTOR	7	OFFSETS:	-0.6073620E-01	-0.2271010E-01	0.3033300E-02	0.2605410E-01	0.5262825	0.5280746	
		GAINS:	0.4285845	0.3569165	0.3083981	0.2650113	-0.6777846	-0.6811422	
DETECTOR	8	OFFSETS:	-0.5987640E-01	-0.2461550E-01	0.5089000E-02	0.3174230E-01	0.5228335	0.5248264	
		GAINS:	0.4380113	0.3698357	0.3124033	0.2608706	-0.6686329	-0.6924859	
DETECTOR	9	OFFSETS:	-0.5640410E-01	-0.2536150E-01	0.4667900E-02	0.3321290E-01	0.5210618	0.5228211	
		GAINS:	0.4360635	0.3753809	0.3166788	0.2608781	-0.6927794	-0.6962188	BAND 2
DETECTOR	10	OFFSETS:	-0.5449460E-01	-0.2156940E-01	0.4683000E-03	0.2955910E-01	0.5222849	0.5237499	
		GAINS:	0.4286624	0.3648455	0.3221315	0.2657467	-0.6892716	-0.6921114	
DETECTOR	11	OFFSETS:	-0.6550580E-01	-0.2730500E-01	0.6767000E-03	0.2320630E-01	0.5333157	0.5358111	
		GAINS:	0.4249166	0.3550025	0.3037907	0.2625574	-0.6710319	-0.6752328	
DETECTOR	12	OFFSETS:	-0.6302850E-01	-0.2749620E-01	0.3275500E-02	0.2745940E-01	0.5290809	0.5307084	
		GAINS:	0.4304259	0.3638409	0.3061781	0.2608597	-0.6791260	-0.6821756	
DETECTOR	13	OFFSETS:	-0.5633750E-01	-0.2146400E-01	0.9054400E-02	0.3930820E-01	0.5128413	0.5185965	
		GAINS:	0.4018272	0.3389892	0.2839987	0.2294848	-0.6237667	-0.6305326	
DETECTOR	14	OFFSETS:	-0.5565900E-01	-0.2301500E-01	0.9313500E-02	0.3859700E-01	0.5137771	0.5169862	
		GAINS:	0.4104207	0.3501585	0.2904791	0.2364209	-0.6407773	-0.6467015	
DETECTOR	15	OFFSETS:	-0.5909790E-01	-0.2957550E-01	0.2990700E-02	0.3609760E-01	0.5230393	0.5265452	
		GAINS:	0.4111196	0.3573589	0.2980555	0.2377676	-0.6489586	-0.6553429	BAND 3
DETECTOR	16	OFFSETS:	-0.5890460E-01	-0.2356640E-01	0.8523200E-02	0.3598600E-01	0.5172936	0.5206682	
		GAINS:	0.4195329	0.3538085	0.2941260	0.2430488	-0.6521198	-0.6583961	
DETECTOR	17	OFFSETS:	-0.5729180E-01	-0.2311620E-01	0.1103720E-01	0.3762870E-01	0.5140637	0.5176793	
		GAINS:	0.4250826	0.3602161	0.2953913	0.2449197	-0.6593733	-0.6662358	
DETECTOR	18	OFFSETS:	-0.5744090E-01	-0.2168710E-01	0.9675900E-02	0.3829170E-01	0.5138956	0.5172643	
		GAINS:	0.4148560	0.3486704	0.2906130	0.2376407	-0.6427722	-0.6490080	
DETECTOR	19	OFFSETS:	-0.7643870E-01	-0.3634200E-01	-0.1703500E-02	0.3293920E-01	0.5399743	0.5415704	
		GAINS:	0.4644912	0.3878804	0.3216975	0.2555075	-0.7132646	-0.7163138	
DETECTOR	20	OFFSETS:	-0.7675450E-01	-0.3728760E-01	-0.2027100E-02	0.3228370E-01	0.5409477	0.5428379	
		GAINS:	0.4657200	0.3902111	0.3227499	0.2571054	-0.7160860	-0.7197023	
DETECTOR	21	OFFSETS:	-0.7632510E-01	-0.3855000E-01	-0.1967000E-02	0.3442040E-01	0.5398450	0.5425785	
		GAINS:	0.4301274	0.3632604	0.2985036	0.2340937	-0.6605740	-0.6654124	BAND 4
DETECTOR	22	OFFSETS:	-0.7966350E-01	-0.3861690E-01	-0.3831400E-02	0.3020800E-01	0.5452149	0.5466886	
		GAINS:	0.4643362	0.3869625	0.3213909	0.2572265	-0.7135698	-0.7163477	
DETECTOR	23	OFFSETS:	-0.7559100E-01	-0.3835500E 01	-0.4270600E-02	0.3437560E-01	0.5397990	0.5440425	
		GAINS:	0.5070408	0.4291074	0.3577690	0.2768829	-0.7809597	-0.7898412	
DETECTOR	24	OFFSETS:	-0.7505930E-01	-0.3821360E-01	-0.3845400E 02	0.3385480E-01	0.5394332	0.5438306	
		GAINS:	0.5010801	0.4247016	0.3534583	0.2753091	-0.7727181	-0.7818332	

Table B-7a

Landsat-5 Lamp B (Redundant)-High Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

			FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR	1	OFFSETS:	-0.6238000E-01	-0.2763990E-01	0.3023700E-02	0.3154310E-01	0.5280964	0.5273558	BAND 1
		GAINS:	0.4526473	0.3839932	0.3233950	0.2670348	-0.7142659	-0.7128026	
DETECTOR	2	OFFSETS:	-0.6151190E-01	-0.3264210E-01	0.1463600E-02	0.2447550E-01	0.5345061	0.5337071	
		GAINS:	0.4476504	0.3910122	0.3241027	0.2789571	-0.7216434	-0.7200762	
DETECTOR	3	OFFSETS:	-0.6242400E-01	-0.3329110E-01	0.9973000E-03	0.2458610E-01	0.5355970	0.5345342	
		GAINS:	0.4845050	0.4228916	0.3503745	-0.3004874	-0.7802521	-0.7780048	
DETECTOR	4	OFFSETS:	-0.5867740E-01	-0.3322360E-01	0.1015700E-02	0.3256720E-01	0.5295542	0.5287627	
		GAINS:	0.5098363	0.4522478	0.374816	0.3033967	-0.8210241	-0.8192329	
DETECTOR	5	OFFSETS:	-0.5946760E-01	-0.2694120E-01	0.1238000E-02	0.2961390E-01	0.5284706	0.5270853	
		GAINS:	0.5039753	0.4314851	0.3686833	0.3054430	-0.8063357	-0.8032480	
DETECTOR	6	OFFSETS:	-0.6513230E-01	-0.3167350E-01	-0.3140700E-02	0.2632400E-01	0.5374573	0.5361637	
		GAINS:	0.5045273	0.4317025	0.3695990	0.3054665	-0.8070529	-0.8042381	
DETECTOR	7	OFFSETS:	-0.9269790E-01	-0.5261880E-01	-0.1739160E-01	0.1605420E-01	0.5737884	0.5728652	BAND 2
		GAINS:	0.4365664	0.3691051	0.3098097	0.2535135	-0.6852724	-0.6837187	
DETECTOR	8	OFFSETS:	-0.8865340E-01	-0.4815420E-01	-0.1435590E-01	0.1018320E-01	0.5709989	0.5699801	
		GAINS:	0.4437884	0.3733941	0.3146470	0.2719933	-0.7027945	-0.7010239	
DETECTOR	9	OFFSETS:	-0.8579210E-01	-0.4602180E-01	-0.1663490E-01	0.9228400E-02	0.5702790	0.5689393	
		GAINS:	0.4593017	0.3869460	0.3334821	0.2864287	-0.7342958	-0.7318588	
DETECTOR	10	OFFSETS:	-0.8667070E-01	-0.4478630E-01	-0.1636680E-01	0.1026190E-01	0.5690230	0.5685367	
		GAINS:	0.4636009	0.3869525	0.3349455	0.2862157	-0.7362993	-0.7354093	
DETECTOR	11	OFFSETS:	-0.8689480E-01	-0.4861900E-01	-0.2201020E-01	0.9193700E-02	0.5742438	0.5740840	
		GAINS:	0.4880283	0.4143593	0.3631451	0.3030871	-0.7844616	-0.7841540	
DETECTOR	12	OFFSETS:	-0.8741020E-01	-0.4567960E-01	-0.1499750E-01	0.9287700E-02	0.5698195	0.5689796	
		GAINS:	0.4879782	0.4078308	0.3489031	0.3022608	-0.7742917	-0.7726787	
DETECTOR	13	OFFSETS:	-0.6318220E-01	-0.2412090E-01	0.4754200E-02	0.3214620E-01	0.5238272	0.5265750	BAND 3
		GAINS:	0.4327738	0.3592265	0.3048586	0.2532833	-0.6724839	-0.6776575	
DETECTOR	14	OFFSETS:	-0.5785220E-01	-0.2430500E-01	0.4143000E-02	0.3295360E-01	0.5211931	0.5238675	
		GAINS:	0.4302730	0.3659822	0.3114641	0.2562505	-0.6794220	-0.6845473	
DETECTOR	15	OFFSETS:	-0.5779080E-01	-0.2085420E-01	0.4853500E-02	0.2897040E-01	0.5208398	0.5239806	
		GAINS:	0.4417974	0.3690954	0.3184952	0.2710263	-0.6971158	-0.7032977	
DETECTOR	16	OFFSETS:	-0.5765810E-01	-0.2429560E-01	0.2086900E-02	0.3128730E-01	0.5223201	0.5262579	
		GAINS:	0.4583794	0.3902072	0.3362977	0.2766303	-0.7267337	-0.7347803	
DETECTOR	17	OFFSETS:	-0.5659380E-01	-0.2575950E-01	0.6076400E-02	0.3189140E-01	0.5206831	0.5237032	
		GAINS:	0.4447962	0.3833657	0.3199399	0.2685093	-0.7052968	-0.7113136	
DETECTOR	18	OFFSETS:	-0.5762630E-01	0.2547720E-01	0.6003300E-02	0.2970650E-01	0.5222222	0.5251715	
		GAINS:	0.4478003	0.3836145	0.3207639	0.2734404	-0.7098653	-0.7157537	
DETECTOR	19	OFFSETS:	-0.8925430E-01	-0.4926080E-01	-0.4398200E-02	0.2950820E-01	0.5562891	0.5571159	BAND 4
		GAINS:	0.5680575	0.4792867	0.3797068	0.3044459	-0.8648316	-0.8666665	
DETECTOR	20	OFFSETS:	-0.8573960E-01	-0.4847760E-01	-0.7198600E-02	0.2913170E-01	0.5520272	0.5602568	
		GAINS:	0.4927728	0.4200268	0.3394368	0.2685099	-0.7523410	-0.7684075	
DETECTOR	21	OFFSETS:	-0.9065390E-01	-0.4889830E-01	-0.1003300E-02	0.3198610E-01	0.5537046	0.5548656	
		GAINS:	0.5563134	0.4660403	0.3624944	0.2911729	-0.8367558	-0.8392664	
DETECTOR	22	OFFSETS:	-0.8612670E-01	-0.4836560E-01	-0.9307000E-03	0.2866300E-01	0.5512880	0.5554719	
		GAINS:	0.4973451	0.4230543	0.3297310	0.2715084	-0.7567041	-0.7649354	
DETECTOR	23	OFFSETS:	-0.8973290E-01	-0.5100940E-01	-0.5962100E-02	0.2645190E-01	0.5549683	0.5652848	
		GAINS:	0.5058244	0.4294303	0.3405616	0.2766155	-0.7660400	-0.7863923	
DETECTOR	24	OFFSETS:	-0.8956550E-01	-0.4803150E-01	-0.5834200E-02	0.3120860E-01	0.5555444	0.5566785	
		GAINS:	0.5582784	0.4677844	0.3758450	0.2951365	-0.8472871	-0.8497579	

Table B-8

Landsat-4 Lamp B (Redundant)-Low Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

		FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR 1	OFFSETS:	-0.5037410E-01	-01860890E-01	0.7132600E-02	0.3375870E-01	0.5132428	0.5148494	BAND 1
	GAINS:	0.3994784	0.3410130	0.2936339	0.2446260	−0.5132428	-0.6408542	
DETECTOR 2	OFFSETS:	0.4925510E-01	0.1736830E-01	0.7233600E-02	0.3321810E-01	0.5122860	0.5138967	
	GAINS:	0.4148498	0.3535858	0.3063182	0.2563942	-0.6040353	-0.6671127	
DETECTOR 3	OFFSETS:	-0.5137230E-01	-0.1975810E-01	0.9809800E-02	0.3239550E-01	0.5137580	0.5151665	
	GAINS:	0.4072016	0.3481600	0.2929401	0.2507598	-0.6482154	-0.6508459	
DETECTOR 4	OFFSETS:	-0.4935090E-01	-0.1889950E-01	0.7552100E-02	0.3247990E-01	0.5133566	0.5148619	
	GAINS:	0.4148422	0.3563626	0.3055648	0.2576932	-0.6657859	-0.6686767	
DETECTOR 5	OFFSETS:	-0.5100680E-01	-0.1885640E-01	0.7868900E-02	0.3468700E-01	0.5129884	0.5142983	
	GAINS:	0.4120424	0.3511810	0.3005557	0.2498288	-0.6555641	-0.6580436	
DETECTOR 6	OFFSETS:	-0.4957090E-01	-0.1917420E-01	0.7952300E-02	0.3222310E-01	0.5134971	0.5150726	
	GAINS:	0.4107260	0.3529894	0.3014650	0.2563645	-0.6587762	-0.6617688	
DETECTOR 7	OFFSETS:	-0.5339620E-01	-0.2134640E-01	0.1028790E-01	0.4057520E-01	0.5102282	0.5136505	BAND 2
	GAINS:	0.3722690	0.3180521	0.2645379	0.2133024	-0.5811859	-0.5869752	
DETECTOR 8	OFFSETS:	-0.5284440E-01	-0.2093220E-01	0.9033300E-02	0.3820700E-01	0.5113385	0.5151971	
	GAINS:	0.3760740	0.3214008	0.2700628	0.2200814	-0.5906040	-0.5971149	
DETECTOR 9	OFFSETS:	-0.5240090E-01	-0.1991060E-01	0.1153540E-01	0.3671770E-01	0.5103191	0.5137388	
	GAINS:	0.3780433	0.3219748	0.2677090	0.2242520	-0.5930387	-0.5989401	
DETECTOR 10	OFFSETS:	-0.5271360E-01	-0.2110650E-01	0.1046320E-01	0.4201610E-01	0.5090710	0.5122694	
	GAINS:	0.3762394	0.3220329	0.2678906	0.213770	-0.5672270	-0.5927122	
DETECTOR 11	OFFSETS:	-0.5363690E-01	-0.2252990E-01	0.8717800E-02	0.3932520E-01	0.5122316	0.5158919	
	GAINS:	0.3609101	0.3099493	0.2587582	0.2086159	-0.5661186	-0.5721151	
DETECTOR 12	OFFSETS:	-0.5340150E-01	-0.2176900E-01	0.9007800E-02	0.3923330E-01	0.5113417	0.5155867	
	GAINS:	0.3669298	0.3141873	0.2628717	0.2124753	-0.5746930	-0.5817708	
DETECTOR 13	OFFSETS:	-0.5633750E-01	-0.2146400E-01	0.9054400E-02	0.3930820E-01	0.5128416	0.5165965	BAND 3
	GAINS:	0.4018272	0.3389892	0.2839987	0.2294848	-0.6237667	-0.6305326	
DETECTOR 14	OFFSETS:	-0.5565900E-01	-0.2301500E-01	0.9313500E-02	0.3859700E-01	0.5137771	0.5169862	
	GAINS:	0.4104207	0.3501585	0.2904791	0.2364209	-0.6407773	-0.6467015	
DETECTOR 15	OFFSETS:	-0.5909790E-01	-0.2957560E-01	0.2990700E-02	0.3609760E-01	0.5230393	0.5265452	
	GAINS:	0.4111196	0.3573589	0.2980655	0.2377676	-0.6489586	-0.6553429	
DETECTOR 16	OFFSETS:	-0.5890460E-01	-0.2356640E-01	0.8523200E-02	0.3598600E-01	0.5172936	0.5206682	
	GAINS:	0.4195329	0.3538085	0.2941260	0.2430488	-0.6521198	-0.6583961	
DETECTOR 17	OFFSETS:	-0.5729180E-01	-0.2311620E-01	0.1103720E-01	0.3762870E-01	0.5140637	0.5176793	
	GAINS:	0.4250826	0.3602161	0.2953913	0.2449197	-0.6593733	-0.6662356	
DETECTOR 18	OFFSETS:	-0.5744090E-01	-0.2168710E-01	0.9675900E-02	0.3829170E-01	0.5138956	0.5172643	
	GAINS:	0.4148560	0.3486704	0.2906130	0.2376407	-0.6427722	-0.6490080	
DETECTOR 19	OFFSETS:	-0.7643870E-01	-0.3634200E-01	0.1703500E-02	0.3293920E-01	0.5399743	0.5415704	BAND 4
	GAINS:	0.4644912	0.3878804	0.3216975	0.2555075	-0.7132646	-0.7163138	
DETECTOR 20	OFFSETS:	-0.7675450E-01	-0.3728760E-01	-0.2027100E-02	0.3228370E-01	0.5409477	0.5428379	
	GAINS:	0.4657200	0.3902111	0.3227499	0.2571054	-0.7160860	-0.7197023	
DETECTOR 21	OFFSETS:	-0.7632510E-01	-0.3855000E-01	-0.1967000E-02	0.3442040E-01	0.5398450	0.5425785	
	GAINS:	0.4301274	0.3632604	0.2985036	0.2340937	-0.6605740	-0.6654124	
DETECTOR 22	OFFSETS:	-0.7966350E-01	-0.3861690E-01	-0.3831400E-02	0.3020800E-01	0.5452149	0.5466886	
	GAINS:	0.4643362	0.3869625	0.3213909	0.2572266	-0.7135698	-0.7163477	
DETECTOR 23	OFFSETS:	-0.7559100E-01	-0.3835500E-01	0.4270600E-02	0.3437560E-01	0.5397990	0.5440425	
	GAINS:	0.5070408	0.4291074	0.3577690	0.2768829	-0.7809597	-0.7898412	
DETECTOR 24	OFFSETS:	-0.7505930E-01	-0.3821360E-01	-0.3845400E-02	0.3385480E-01	0.5394332	0.5438306	
	GAINS:	0.5010801	0.4247016	0.[illegible]4583	0.2753091	−0.7727181	-0.7818332	

Table B-8a

Landsat-5 Lamp B (Redundant)-Low Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values

		FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR 1	OFFSETS:	-0.5001570E-01	-0.2369810E-01	0.2856100E-02	0.3250280E-01	0.5173144	0.5210404	BAND 1
	GAINS:	0.4053097	0.3560819	0.3064117	0.2509567	-0.6558953	-0.6628648	
DETECTOR 2	OFFSETS:	-0.4856030E-01	-0.2317560E-01	0.3150600E-02	0.2966690E-01	0.5178251	0.5210932	
	GAINS:	0.4027829	0.3552770	0.3060094	0.2563859	-0.6571695	-0.6632856	
DETECTOR 3	OFFSETS:	-0.4764370E-01	-0.2189600E-01	0.2197800E-02	0.3042840E-01	0.5174268	0.5194866	
	GAINS:	0.4316728	0.3798107	0.3312801	0.2744167	-0.7065157	-0.7106646	
DETECTOR 4	OFFSETS:	-0.4743660E-01	-0.2012040E-01	0.3498500E-02	0.2835330E-01	0.5161018	0.5196031	
	GAINS:	0.4610670	0.4022420	0.3513792	0.2978549	-0.7525015	-0.7600416	
DETECTOR 5	OFFSETS:	-0.4857320E-01	-0.1966870E-01	0.3539600E-02	0.3018490E-01	0.5163416	0.5181754	
	GAINS:	0.4520929	0.3913816	0.3426344	0.2866682	-0.7344626	-0.7383143	
DETECTOR 6	OFFSETS:	-0.5003220E-01	-0.2242120E-01	0.2678900E-02	0.2939430E-01	0.5191884	0.5211920	
	GAINS:	0.4483180	0.3911949	0.3392665	0.2839963	-0.7293153	-0.7334603	
DETECTOR 7	OFFSETS:	-0.4803480E-01	-0.2288530E-01	0.3025100E-02	0.3213820E-01	0.5161389	0.5196176	BAND 2
	GAINS:	0.3457282	0.3052305	0.2635077	0.2166275	-0.5627460	-0.5683478	
DETECTOR 8	OFFSETS:	-0.4993830E-01	-0.2418070E-01	0.3319800E-02	0.3199350E-01	0.5180123	0.5207926	
	GAINS:	0.3630509	0.3198787	0.2737851	0.2257252	-0.5888898	-0.5935500	
DETECTOR 9	OFFSETS:	-0.4822210E-01	-0.2106920E-01	0.4999000E-02	0.2888360E-01	0.5158523	0.5195554	
	GAINS:	0.3724751	0.3254099	0.2802249	0.2388247	-0.6052577	-0.6116765	
DETECTOR 10	OFFSETS:	-0.4820620E-01	-0.2089950E-01	0.6690200E-02	0.2833100E-01	0.5152087	0.5188754	
	GAINS:	0.3730633	0.3256532	0.2777518	0.2401789	-0.6051403	-0.6115065	
DETECTOR 11	OFFSETS:	-0.4920320E-01	-0.2022580E-01	0.6043100E-02	0.2630410E-01	0.5168766	0.5202054	
	GAINS:	0.3973901	0.3440462	0.2956885	0.2583904	-0.6446934	-0.6508216	
DETECTOR 12	OFFSETS:	-0.5077510E-01	-0.1899380E-01	0.5459600E-02	0.3086290E-01	0.5150351	0.5184108	
	GAINS:	0.3952102	0.3374463	0.2930011	0.2468294	-0.6331755	-0.6393110	

Table B-8a
Landsat-5 Lamp B (Redundant)-Low Gain Offsets (C_i') and Gains (D_i') for Six Cal Wedge Values (Continued)

		FOR 1ST VALUE	FOR 2ND VALUE	FOR 3RD VALUE	FOR 4TH VALUE	FOR 5TH VALUE	FOR 6TH VALUE	
DETECTOR 13	OFFSETS:	-0.6318220E-01	-0.2412090E-01	0.4754200E-02	0.3214620E-01	0.5238272	0.5265750	BAND 3
	GAINS:	0.4327738	0.3592265	0.3048586	0.2532833	-0.6724839	-0.6776575	
DETECTOR 14	OFFSETS:	-0.5785220E-01	-0.2430500E-01	0.4143000E-02	0.3295360E-01	0.5211931	0.5238675	
	GAINS:	0.4302730	0.3659822	0.3114641	0.2562505	-0.6794220	-0.6845473	
DETECTOR 15	OFFSETS:	-0.5779080E-01	-0.2085420E-01	0.4853500E-02	0.2897040E-01	0.5208398	0.5239806	
	GAINS:	0.4417974	0.3690954	0.3184952	0.2710263	-0.6971158	-0.7032977	
DETECTOR 16	OFFSETS:	-0.5765810E-01	-0.2429560E-01	0.2086900E-02	0.3128730E-01	0.5223201	0.5262579	
	GAINS:	0.4583794	0.3902072	0.3362977	0.2766303	-0.7267337	-0.7347803	
DETECTOR 17	OFFSETS:	-0.5659380E-01	-0.2575950E-01	0.6076400E-02	0.3189140E-01	0.5206831	0.5237032	
	GAINS:	0.4447962	0.3833657	0.3199399	0.2685093	-0.7052968	-0.7113136	
DETECTOR 18	OFFSETS:	-0.5762630E-01	-0.2547720E-01	0.6003300E-02	0.2970650E-01	0.5222222	0.5251715	
	GAINS:	0.4478003	0.3836145	0.3207639	0.2734404	-0.7098653	-0.7157537	
DETECTOR 19	OFFSETS:	-0.8925430E-01	-0.4926080E-01	-0.4398200E-02	0.2950820E-01	0.5562891	0.5571159	BAND 4
	GAINS:	0.5680575	0.4792867	0.3797068	0.3044459	-0.8648316	-0.8666665	
DETECTOR 20	OFFSETS:	-0.8573960E-01	-0.4847760E-01	-0.7198600E-02	0.2913170E-01	0.5520272	0.5602568	
	GAINS:	0.4927728	0.4200268	0.3394368	0.2685099	-0.7523410	-0.7684075	
DETECTOR 21	OFFSETS:	-0.9065390E-01	-0.4889830E-01	-0.1003300E-02	0.3198610E-01	0.5537046	0.5548656	
	GAINS:	0.5563134	0.4660403	0.3624944	0.2911729	-0.8367558	-0.8392664	
DETECTOR 22	OFFSETS:	-0.8612670E-01	-0.4836560E-01	-0.9307000E-03	0.2866300E-01	0.5512880	0.5554719	
	GAINS:	0.4973451	0.4230543	0.3297310	0.2715084	-0.7567041	-0.7649354	
DETECTOR 23	OFFSETS:	-0.8973290E-01	-0.5100940E-01	-0.5962100E-02	0.2646190E-01	0.5549683	0.5652848	
	GAINS:	0.5058244	0.4294303	0.3405616	0.2766155	-0.7660400	-0.7863923	
DETECTOR 24	OFFSETS:	-0.8956550E-01	-0.4803150E-01	-0.5834200E-02	0.3120860E-01	0.5555444	0.5566785	
	GAINS:	0.5582784	0.4677844	0.3758450	0.2951365	-0.8472871	-0.8497579	

Tables B-9, B-9a, B-10, and B-10a present the M and A values for each sensor operating mode. The M and A value sets provided include:

a. Postlaunch calibration values for compressed mode operation using Lamp A. (Band 4 values apply to all Lamp A modes.)

   Nominal values (M = 1.0, A = 0.0) are provided where postlaunch calibration has not been performed.

b. Normalization values which result in matching the corrected data to that from previous Landsat MSS instruments.

B5. RADIANCE RANGE

The radiometric ranges which correspond to the calibration data presented in Tables B-3 through B-10a are defined in Tables B-11 and B-11a.

Table B-9
Landsat-4 Multiplicative Modifiers

HIGH GAIN, LINEAR, LAMP A

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2	(1)
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9910	1.0120	0.9950	1.0050	0.9870	1.0090	Band 4	

LOW GAIN, LINEAR, LAMP A

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2	(1)
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9910	1.0120	0.9950	1.0050	0.9870	1.0090	Band 4	

HIGH GAIN, COMPRESSED, LAMP A

Band 1	0.9989	1.0080	0.9808	0.9815	1.0140	0.9961	0.9938	1.0000	1.0050	0.9943	1.0090	0.9989	Band 2	(1)
Band 3	0.8670	0.8700	0.8630	0.8600	0.8550	0.8630	0.9910	1.0120	0.9950	1.0050	0.9870	1.0090	Band 4	

LOW GAIN, COMPRESSED, LAMP A

Band 1	0.9310	0.9210	0.9180	0.9130	0.9190	0.9160	0.9900	0.9940	1.0050	0.9860	1.0200	1.0030	Band 2	(1)
Band 3	0.8670	0.8700	0.8630	0.8600	0.8550	0.8630	0.9910	1.0120	0.9950	1.0050	0.9870	1.0090	Band 4	

Band 1	0.9560	0.9457	0.9408	0.9375	0.9437	0.9406	0.9017	0.9864	0.9154	0.8981	0.9291	0.9136	Band 2	(2)
Band 3	0.9451	0.9483	0.9407	0.9374	0.9320	0.9407	0.8606	0.8788	0.8641	0.8728	0.8672	0.8763	Band 4	

HIGH GAIN, LINEAR, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

LOW GAIN, LINEAR, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

HIGH GAIN, COMPRESSED, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

LOW GAIN, COMPRESSED, LAMP B

Band 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 2
Band 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	Band 4

LEGEND:

Band 1	DET 1	DET 2	DET 3	DET 4	DET 5	DET 6	DET 7	DET 8	DET 9	DET 10	DET 11	DET 12	Band 2
Band 3	DET 13	DET 14	DET 15	DET 16	DET 17	DET 18	DET 19	DET 20	DET 21	DET 22	DET 23	DET 24	Band 4

(1) POSTLAUNCH VALUES

(2) NORMALIZATION VALUES

Table B-9a
Landsat-5 Multiplicative Modifiers

HIGH GAIN, LINEAR, LAMP A

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

LOW GAIN, LINEAR, LAMP A

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

HIGH GAIN, COMPRESSED, LAMP A

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

LOW GAIN, COMPRESSED, LAMP A

BAND 1	0.9889	1.0351	0.9918	0.9946	0.9984	1.0053	1.0014	0.9987	1.0087	1.0026	0.9796	1.0066	BAND 2	1
BAND 3	0.9952	1.0126	1.0055	0.9832	1.0036	1.0005	0.9997	0.9953	1.0015	1.0105	0.9971	0.9958	BAND 4	
BAND 1	1.1114	1.1163	1.1146	1.1179	1.1220	1.1299	1.0529	1.0501	1.0605	1.0541	1.0300	1.0584	BAND 2	2
BAND 3	1.0506	1.0689	1.0614	1.0379	1.0595	1.0561	0.9612	0.9570	0.9630	0.9715	0.9587	0.9575	BAND 4	

HIGH GAIN, LINEAR, LAMP B

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

1 POSTLAUNCH VALUES

2 NORMALIZATION VALUES

Table B-9a
Landsat-5 Multiplicative Modifiers (Continued)

LOW GAIN, LINEAR, LAMP B

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

HIGH GAIN, COMPRESSED, LAMP B

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

LOW GAIN, COMPRESSED, LAMP B

BAND 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 2
BAND 3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	BAND 4

LEGEND:

BAND 1	DET 1	DET 2	DET 3	DET 4	DET 5	DET 6	DET 7	DET 8	DET 9	DET 10	DET 11	DET 12	BAND 2
BAND 3	DET 13	DET 14	DET 15	DET 16	DET 17	DET 18	DET 19	DET 20	DET 21	DET 22	DET 23	DET 24	BAND 4

Table B-10
Landsat-4 Additive Modifiers

HIGH GAIN, LINEAR, LAMP A

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2	(1)
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1360	-0.1580	-0.2620	-0.0430	+0.0800	-0.1760	BAND 4	

LOW GAIN, LINEAR, LAMP A

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2	(1)
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	+0.1360	-0.1580	-0.2620	-0.0430	+0.0800	-0.1760	BAND 4	

HIGH GAIN, COMPRESSED, LAMP A

BAND 1	0.4803	-0.6869	0.2802	0.1141	-0.0369	-0.1405	0.4768	-0.8926	-1.2940	0.0670	1.0350	0.5394	BAND 2	(1)
BAND 3	-0.8480	-0.4840	0.8790	0.6200	0.0070	-0.1440	0.1360	-0.1580	-0.2620	-0.0430	0.0800	-0.1760	BAND 4	

LOW GAIN, COMPRESSED, LAMP A

BAND 1	-0.1210	-0.0930	-0.0290	0.1560	0.1060	-0.0370	0.0660	0.1260	-0.3110	-0.0750	0.2690	0.0260	BAND 2	(1)
BAND 3	-0.8480	-0.4840	0.8790	0.6200	0.0070	-0.1440	0.1360	-0.1580	-0.2620	-0.0430	0.0800	-0.1760	BAND 4	
BAND 1	0.7866	0.8146	0.8786	1.0346	1.0136	0.8706	-0.1560	-0.0950	-0.5320	-0.2960	0.0480	-0.1950	BAND 2	(2)
BAND 3	-0.2823	0.1017	1.4647	1.2067	0.5927	0.4417	0.7696	0.4656	0.3616	0.5806	0.7036	0.4476	BAND 4	

HIGH GAIN, LINEAR, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LOW GAIN, LINEAR, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

HIGH GAIN, COMPRESSED, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LOW GAIN, COMPRESSED, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LEGEND:

BAND 1	DET 1	DET 2	DET 3	DET 4	DET 5	DET 6	DET 7	DET 8	DET 9	DET 10	DET 11	DET 12	BAND 2
BAND 3	DET 13	DET 14	DET 15	DET 16	DET 17	DET 18	DET 19	DET 20	DET 21	DET 22	DET 23	DET 24	BAND 4

(1) POSTLAUNCH VALUES

(2) NORMALIZATION VALUES

Table B-10a
Landsat-5 Additive Modifiers

HIGH GAIN, LINEAR, LAMP A

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LOW GAIN, LINEAR, LAMP A

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

HIGH GAIN, COMPRESSED, LAMP A

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LOW GAIN, COMPRESSED, LAMP A

BAND 1	0.1507	-0.2240	0.1089	-0.0736	-0.7735	-0.0930	-0.1618	-0.4751	0.4656	0.4427	0.2091	-0.1056	BAND 2	1
BAND 3	-0.3120	-0.3350	-0.0828	0.0650	0.1675	0.4694	0.0592	-0.0513	-0.3889	-0.0239	0.4284	-0.0336	BAND 4	
BAND 1	-0.5091	-0.8544	-0.5490	-0.7296	-1.4270	-0.7420	-0.1127	-0.4259	0.0953	0.4918	0.2593	-0.0567	BAND 2	2
BAND 3	0.0627	0.0333	0.2881	0.4444	0.5391	0.8422	1.2934	1.1883	0.8431	1.1973	1.6658	1.2055	BAND 4	

HIGH GAIN, LINEAR, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

1 POSTLAUNCH VALUES

2 NORMALIZATION VALUES

Table B-10a
Landsat-5 Additive Modifiers (Continued)

LOW GAIN, LINEAR, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

HIGH GAIN, COMPRESSED, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LOW GAIN, COMPRESSED, LAMP B

BAND 1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 2
BAND 3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	BAND 4

LEGEND:

BAND 1	DET 1	DET 2	DET 3	DET 4	DET 5	DET 6	DET 7	DET 8	DET 9	DET 10	DET 11	DET 12	BAND 2
BAND 3	DET 13	DET 14	DET 15	DET 16	DET 17	DET 18	DET 19	DET 20	DET 21	DET 22	DET 23	DET 24	BAND 4

Table B-11
Landsat-4 Radiometric Range of MSS Data

		R_{min}*		R_{max}*		
	Band	At Launch Postlaunch	Normalization	At Launch	Postlaunch	Normalization
Low Gain:	1	0.02	0.04	2.50	2.30	2.38
	2	0.04	0.04	1.80	1.80	1.64
	3	0.04	0.05	1.50	1.30	1.42
	4	0.10	0.12	4.00	4.00	3.49
High Gain:	1	0.01	0.01	0.80	0.80	0.80
	2	0.03	0.03	0.60	0.60	0.60

*R in milliwatt/cm^2/micron/steradian

Table B-11a
Landsat-5 Radiometric Range of MSS Data

		R_{MIN}*		R_{MAX}*	
	BAND	AT LAUNCH POSTLAUNCH	NORMALIZATION	AT LAUNCH POSTLAUNCH	NORMALIZATION
LOW GAIN:	1	0.04	0.04	2.40	2.38
	2	0.03	0.04	1.70	1.64
	3	0.04	0.05	1.50	1.42
	4	0.06	0.12	3.80	3.49
HIGH GAIN:	1	0.02	0.02	0.80	0.80
	2	0.02	0.02	0.60	0.60

*R IN MILLIWATT/CM^2/MICRON/STERADIAN

APPENDIX C

TM DATA PROCESSING CONSTANTS

APPENDIX C

TM DATA PROCESSING CONSTANTS

C1. MIRROR POSITION PROFILES

The prelaunch mirror position profiles are specified by fifth-order polynomials. The along- and across-scan polynomial profile coefficients for the various operating modes of the Landsat-4 and -5 scan mirrors are provided in Tables C-1 and C-1a. The across-scan profile is derived from the scan mirror across-scan linearity. The forward scan profile polynomials start at scan-start and end at scan-end. The reverse profile polynomials start at scan-end and end at scan-start. Scan time has been normalized to 0.060743 second. A second-order correction, which is based on the first-half and second-half scan-time error, must be applied to these profiles (see Appendix E). This scan-error information is included in the TM wideband data.

The TM midscan pulse defines the instrument optical axis. The forward and reverse scan angle monitor pulses are nominally at the same angular location relative to midscan location. (The detector delay data provided Tables in C-2 and C-2a include whatever difference there is in pulse location between forward and reverse scans.)

The scan-line corrector (SLC) velocity profile will be the same for forward and reverse scan mirror assembly scan and is also defined by a fifth-order polynomial which need not be corrected for line length. The best available information shows that all coefficients of the SLC fifth-order polynomial profile (SLC-1 and SLC-2) should be set to zero. The scan line corrector rates in object space are:

Landsat-4	Landsat-5
0.00966 rad/sec for SLC-1	0.00966 rad/sec for SLC-1
0.00961 rad/sec for SLC-2	0.00960 rad/sec for SLC-2

The midscan position of the SLC has a nominal zero cross scan angular displacement.

C2. DETECTOR DELAYS AND BAND OFFSETS

The along-scan detector response data define the overall system delay for each detector and each scan direction. These data define the effective sampling delays due to scan angle monitor delays, channel electronic delays and detector focal plane placement errors. Tables C-2, C-2a, C-3, and C-3a give these detector delays in units of IFOV or 9.611 microseconds for the forward and reverse scan directions, respectively.

Table C-1
Scan-Mirror Profile Along- and Cross-Scan
Data Summary for TM Protoflight Unit
(Landsat-4)

	SME-1		SME-2	
	ALONG SCAN*	**CROSS SCAN**	**ALONG SCAN***	**CROSS SCAN**
FORWARD SCAN				
Polynomial Coefficients:				
a_0 (rad)	3.5702E-7	3.3395E-7	1.3649E-7	2.7113E-7
a_1 (rad/sec)	-2.1869E-3	5.9110E-5	-2.3408E-3	2.7470E-5
a_2 (rad/sec^2)	2.6079E-1	-4.933E-5	2.6000E-1	1.1813E-3
a_3 (rad/sec^3)	-1.1629E+1	-9.9086E-3	-1.1438E+1	-9.7359E-2
a_4 (rad/sec^4)	2.2138E+2	9.7717E-2	2.1761E+2	1.4848E+0
a_5 (rad/sec^5)	-1.4967E+3	1.1866E-1	-1.4707E+3	-0.2997E+0
Scan Angles:				
Start to Mid (μrad)	67157	N/A	67171	N/A
Mid to End (μrad)	67175	N/A	67195	N/A
REVERSE SCAN				
Polynomial Coefficients:				
b_0 (rad)	5.091E-7	2.2088E-7	4.0266E-7	4.5580E-7
b_1 (rad/sec)	3.7036E-3	7.2290E-5	3.6771E-3	6.3702E-5
b_2 (rad/sec^2)	-3.2443E-1	-1.7248E-3	-3.2999E-1	-1.0284E-3
b_3 (rad/sec^3)	1.2888E+1	1.3948E-2	1.3183E+1	-1.6645E-2
b_4 (rad/sec^4)	-2.2970E+2	-2.7076E-2	-2.3509E+2	5.2138E-1
b_5 (rad/sec^5)	1.4638E+3	-1.1315E+0	1.4999E+3	-4.4405E+0
Scan Angles:				
Start to Mid (μrad)	67175	N/A	67195	N/A
Mid to End (μrad)	67157	N/A	67171	N/A

NOTE: SME = Scan mirror electronics
* = SAM mode
All values are defined in mirror space

Table C-1a
Scan-Mirror Profile Along- and Cross-Scan
Data Summary for TM Protoflight Unit
(Landsat-5)

	SME-1		SME-2	
	ALONG SCAN*	CROSS SCAN	ALONG SCAN*	CROSS SCAN
FORWARD SCAN				
Polynomial Coefficients:				
a_0 (rad)	0.0	0.0	0.0	0.0
a_1 (rad/sec)	-2.0846E-3	-1.2639E-4	-1.6484E-3	-1.2101E-4
a_2 (rad/sec^2)	+2.4365E-1	+3.5312E-3	+2.4464E-1	+2.9221E-3
a_3 (rad/sec^3)	-1.1042E+1	-4.8660E-2	-1.1422E+1	-2.9348E-2
a_4 (rad/sec^4)	+2.1349E+2	+5.4476E-1	+2.1987E+2	+3.3941E-1
a_5 (rad/sec^5)	-1.4560E+3	-2.2077E+0	-1.4945E+3	-1.7827E+0
Scan Angles:				
Start to Mid (μrad)	67171	N/A	67182	N/A
Mid to End (μrad)	67159	N/A	67160	N/A
REVERSE SCAN				
Polynomial Coefficients:				
b_0 (rad)	0.0	0.0	0.0	0.0
b_1 (rad/sec)	+2.5179E-3	-9.9308E-5	+3.1143E-3	-9.0740E-5
b_2 (rad/sec^2)	-3.0669E-1	+2.6935E-3	-3.2331E-1	+1.5799E-3
b_3 (rad/sec^3)	+1.3025E+1	-6.8859E-2	+1.3313E+1	-1.3242E-2
b_4 (rad/sec^4)	-2.3212E+2	+1.4509E+0	-2.3650E+2	+2.9615E-1
b_5 (rad/sec^5)	+1.4747E+3	-9.9468E+0	+1.4991E+3	-1.6706E+0
Scan Angles:				
Start to Mid (μrad)	67159	N/A	67160	N/A
Mid to End (μrad)	67171	N/A	67182	N/A

NOTE: SME = Scan mirror electronics
* = SAM mode
All values are defined in mirror space

Table C-2
Landsat-4 Forward Along-Scan Detector Delay in IFOV (9.611 μsec)

DETECTOR	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6 (4 DETECTORS ONLY)	BAND 7
1	1.305	1.315	1.245	1.195	1.510	4.900	1.455
2	1.240	1.475	1.205	1.185	1.360	4.900	1.320
3	1.260	1.270	1.225	1.185	*	4.900	1.425
4	1.235	*	1.190	1.190	1.345	4.900	1.320
5	1.265	1.300	1.245	1.185	1.435	0.0	1.435
6	1.240	1.235	1.250	1.175	1.420	0.0	1.320
7	1.235	1.270	1.240	1.180	1.360	0.0	1.425
8	1.205	1.195	1.255	1.205	1.490	0.0	1.340
9	1.240	1.280	1.165	1.225	1.430	0.0	1.390
10	1.220	1.210	1.190	1.190	1.360	0.0	1.310
11	1.225	1.265	1.205	1.195	1.445	0.0	1.425
12	1.225	1.230	1.245	1.185	1.340	0.0	1.250
13	1.275	1.310	1.235	1.245	1.435	0.0	1.405
14	1.215	1.250	1.265	1.235	1.390	0.0	1.255
15	1.235	1.310	1.275	1.215	1.385	0.0	1.435
16	1.255	1.265	1.280	1.230	1.370	0.0	1.235

*Failed Detector

Table C-2a

Landsat-5 Forward Along-Scan Detector Delay in IFOV (9.611 μsec)

DETECTOR	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6 (4 DETECTORS ONLY)	BAND 7
1	1.460	1.175	1.205	1.260	1.520	4.900	1.189
2	1.470	1.235	1.210	1.245	1.330	4.900	1.055
3	1.450	1.175	1.215	1.260	1.485	4.900	1.130
4	1.465	1.185	1.210	1.250	1.350	4.900	1.115
5	1.495	1.215	1.185	1.250	1.380	0.0	1.150
6	1.425	1.210	1.175	1.195	1.420	0.0	1.100
7	1.455	1.185	1.220	1.210	1.395	0.0	1.170
8	1.415	1.185	1.160	1.225	1.415	0.0	1.125
9	1.450	1.175	1.185	1.225	1.425	0.0	1.220
10	1.425	1.190	1.220	1.205	1.435	0.0	1.100
11	1.450	1.155	1.225	1.225	1.395	0.0	1.180
12	1.455	1.200	1.220	1.205	1.350	0.0	1.035
13	1.495	1.195	1.270	1.250	1.395	0.0	1.115
14	1.430	1.240	1.205	1.230	1.370	0.0	1.040
15	1.515	1.195	1.260	1.285	1.355	0.0	1.125
16	1.455	1.195	1.205	1.255	1.360	0.0	1.075

Table C-3
Landsat-4 Reverse Along-Scan Detector Delay in IFOV (9.611 μsec)

DETECTOR	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6 (4 DETECTORS ONLY)	BAND 7
1	1.370	1.215	1.250	1.200	1.265	4.900	1.195
2	1.315	1.450	1.235	1.195	1.395	4.900	1.345
3	1.300	1.185	1.220	1.190	*	4.900	1.220
4	1.310	*	1.215	1.215	1.360	4.900	1.325
5	1.285	1.215	1.235	1.185	1.275	0.0	1.255
6	1.305	1.175	1.265	1.195	1.450	0.0	1.310
7	1.280	1.165	1.225	1.185	1.235	0.0	1.250
8	1.275	1.140	1.265	1.220	1.545	0.0	1.355
9	1.255	1.185	1.155	1.225	1.325	0.0	1.240
10	1.275	1.150	1.205	1.205	1.430	0.0	1.335
11	1.235	1.175	1.190	1.195	1.360	0.0	1.290
12	1.290	1.165	1.260	1.200	1.440	0.0	1.305
13	1.295	1.170	1.215	1.240	1.365	0.0	1.270
14	1.280	1.185	1.265	1.245	1.515	0.0	1.340
15	1.255	1.205	1.245	1.215	1.320	0.0	1.290
16	1.315	1.185	1.290	1.255	1.555	0.0	1.380

*Failed Detector

Table C-3a
Landsat-5 Reverse Along-Scan Detector Delay in IFOV (9.611 μsec)

DETECTOR	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 6 (4 DETECTORS ONLY)	BAND 7
1	1.075	1.320	1.320	1.285	1.235	4.900	1.395
2	1.085	1.390	1.370	1.290	1.295	4.900	1.535
3	1.030	1.310	1.330	1.290	1.255	4.900	1.390
4	1.090	1.350	1.360	1.295	1.310	4.900	1.259
5	1.055	1.345	1.290	1.265	1.170	0.0	1.440
6	1.045	1.365	1.335	1.235	1.385	0.0	1.259
7	1.005	1.315	1.335	1.275	1.195	0.0	1.250
8	1.035	1.335	1.315	1.260	1.385	0.0	1.575
9	1.015	1.290	1.290	1.225	1.235	0.0	1.545
10	1.045	1.345	1.345	1.275	1.415	0.0	1.605
11	1.015	1.280	1.325	1.235	1.230	0.0	1.475
12	1.060	1.345	1.340	1.235	1.355	0.0	1.555
13	1.065	1.310	1.375	1.255	1.275	0.0	1.425
14	1.040	1.380	1.355	1.255	1.400	0.0	1.590
15	1.070	1.305	1.355	1.285	1.175	0.0	1.450
16	1.050	1.330	1.350	1.280	1.435	0.0	1.670

The along-scan and cross-scan bandcenter location errors (relative to their ideal locations) are given in Table C-4. These location errors result from band placement during focal plane assembly, scan mirror misalignment and focal plane shifts resulting from mechanical vibration stresses.

C3. DRIRU AND ADSA TRANSFER FUNCTIONS

Table C-5 gives the DRIRU Transfer Function Model and the parameters applicable to Landsat-4/-5. This transfer function defines the response of the DRIRU package to mechanical rotational inputs. The same transfer function is used for all axes.

Tables C-6 and C-6a give the ADSA Transfer Function Model and parameters applicable to Landsat-4/-5. These transfer functions define the response of the ADSA package to mechanical rotational inputs.

C4. TM RADIOMETRIC PARAMETERS (BANDS 1-5 AND 7)

Fixed estimates of detector gain and bias for each TM detector are provided in Tables C-7 and C-7a. These estimates are based on prelaunch test results, and can be used to normalize the detectors to a common radiance range on output products. NASA output products are currently normalized to the radiance range defined in Table C-8.

Radiance levels for each calibration lamp configuration and sensor detector are provided for Landsat-4 in Tables C-9 through C-16, and for Landsat-5 in Tables C-17 through C-24. These tables contain data in digital counts, which are related to effective radiance by the gain and bias values defined in Tables C-7 and C-7a. (The data provided in Tables C-9 through C-24 were derived using the 31-minor frame HAC calibration pulse integration algorithm.)

Table C-4
Band Location Errors
(Referenced to the ideal band center locations)

BAND	ALONG SCAN BAND CENTER LOCATION ERROR IN IFOV		CROSS SCAN BAND CENTER LOCATION ERROR IN IFOV	
	LANDSAT-4	LANDSAT-5	LANDSAT-4	LANDSAT-5
1	0.00	0.00	-0.12	+0.04
2	0.00	0.00	-0.10	+0.04
3	0.00	0.00	-0.03	+0.01
4	0.00	0.00	-0.00	0.00
5	-0.58	0.00	-0.02	+0.11
6	-0.70	0.00	+0.06	+0.14
7	-0.58	0.00	-0.08	+0.12

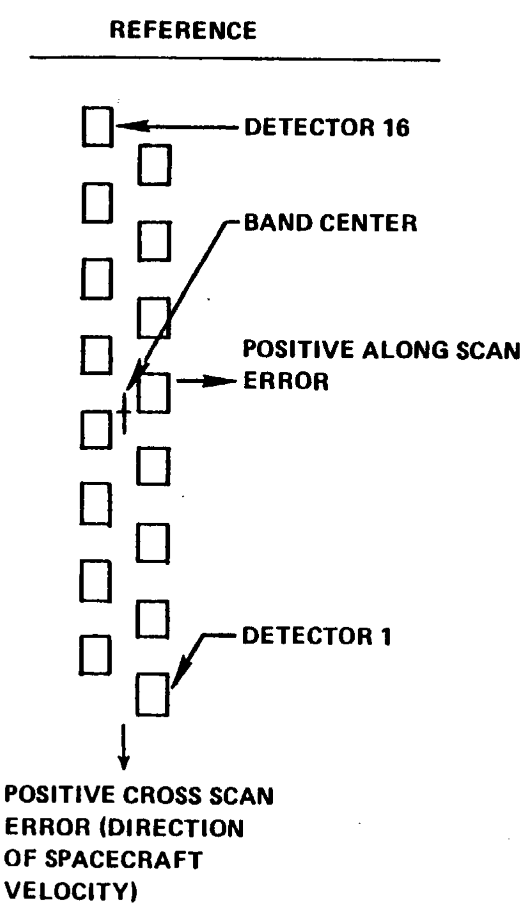


Table C-5
DRIRU Transfer Function (All Channels)

TRANSFER FUNCTION MODEL

```
H(S)  = HNUM/HDEN
HNUM  = AK*(1-P*S)
HDEN  = (1+2*ZETA*S/WN+(S/WN)**2)*(1+TAU*S)
```

WHERE,

```
W  = 2*PI*F
WN = 2*PI*FN
S  = CMPLX (0.0, W)
F  = FREQUENCY IN HERTZ
```

WITH,

LANDSAT-4

```
FN    = 2.2542
ZETA  = 0.7057
TAU   = 12.088E-3
P     = 2.1977E-3
AK    = 1.000173
```

LANDSAT-5

```
FN    = 2.201
ZETA  = 0.7022
TAU   = 11.4468E-3
P     = 3.259E-3
AK    = 1.00518
```

Table C-6
Landsat-4 ADSA Transfer Function

TRANSFER FUNCTION MODEL – H(S) = HNUM/HDEN HNUM = = A5*S**5 + A4*S**4 + A3*S**3 HDEN = S**6 + B5*S**5 + . . . + B1*S + BO
WHERE, S = CMPLX (0.0, 2*PI*F) F = FREQUENCY IN HERTZ
SENSOR 1 A_3 = 4.619E6, A_4 = 5.360E5, A_5 = -3.501E2 B_0 = 7.138E8, B_1 = 9.433E8, B_2 = 2.120E8, B_3 = 1.609E7, B_4 = 6.028E5, B_5 = 9.319E2
SENSOR 2 A_3 = 4.798E6, A_4 = 5.193E5, A_5 = -3.334E2 B_0 = 4.582E8, B_1 = 8.210E9, B_2 = 1.911E8 B_3 = 1.505E7, B_4 = 5.984E5, B_5 = 9.202E2
SENSOR 3 A_3 = 4.079E6, A_4 = 5.247E5, A_5 = -3.408E2 B_0 = 5.2398E8, B_1 = 6.606E8, B_2 = 1.634E8, B_3 = 1.455E7, B_4 = 6.064E5, B_5 = 9.344E2

Table C-6a
Landsat-5 ADSA Transfer Function

Transfer Function Model-

H(S) = HNUM/HDEN
HNUM = A5*S**5 + A4*S**4 + A3*S**3
HDEN = S**6 + B5*S**5 + . . . +B1*S + B0

Where,

S = CMPLX (0.0, 2*PI*F)
F = Frequency in Hertz

SENSOR 1

A3 = +4.3830e+6
A4 = +5.4890e+5
A5 = -3.5290e+2
B0 = +2.8470e+8
B1 = +6.2750e+8
B2 = +1.6550e+8
B3 = +1.4240e+7
B4 = +5.9530e+5
B5 = +9.2030e+2

SENSOR 2

A3 = +5.1110e+6
A4 = +5.6490e+5
A5 = -3.7400e+2
B0 = +3.2140e+8
B1 = +7.1220e+8
B2 = +1.7910e+8
B3 = +1.2780e+7
B4 = +6.0710e+5
B5 = +9.5650e+2

SENSOR 3

A3 = +4.5030e+6
A4 = +5.5060e+5
A5 = -3.5960e+2
B0 = +4.3520e+8
B1 = +6.1010e+8
B2 = +1.5350e+8
B3 = +1.1730e+7
B4 = +6.0310e+5
B5 = +9.4910e+2

Table C-7
Landsat-4 Reflective Band Gain and Bias Data (based on updated prelaunch measurements)

DETECTOR	BAND 1	2	3	4	5	7
GAIN IN COUNTS/(MILLIWATT/CM^2 – SR)						
1	223.5247	102.1713	179.6233	78.3707	382.8460	549.0174
2	225.1800	101.4688	176.6983	77.2636	384.1515	543.5914
3	227.5629	100.1750	176.4983	78.7036	0.0000	547.0129
4	227.5386	101.8000	175.5200	77.3679	388.4920	547.1215
5	225.8614	102.4463	177.0683	77.2293	384.0285	547.1448
6	224.7643	102.2887	177.7233	78.0893	384.4410	543.3244
7	224.0786	100.7087	176.3583	77.2371	387.0625	547.4622
8	225.0771	100.9825	175.5883	77.7250	385.8325	538.3333
9	226.0600	100.9400	177.4200	77.5743	384.8305	547.8144
10	226.5600	101.1588	176.1100	80.6471	384.8445	536.1011
11	224.0871	99.9762	175.9350	76.8079	388.3255	544.3559
12	225.9229	100.1700	177.3833	77.8636	388.7745	547.9014
13	224.2057	101.4575	178.0800	78.9664	387.7745	541.2800
14	225.1214	101.7600	177.3267	77.9364	386.2105	546.1563
15	225.4514	102.4313	179.4883	76.9386	386.5465	541.4759
16	226.7628	99.7400	174.7367	77.3450	388.7090	549.9703
BIAS IN COUNTS						
1	3.1846	2.9940	2.1251	2.5343	3.2768	2.9458
2	2.3958	2.3295	1.5741	1.9376	2.9406	2.3632
3	2.6461	2.4100	1.8939	1.9609	0.0000	2.3685
4	2.5885	2.4445	1.4593	1.8207	2.8519	2.4207
5	2.6723	2.4307	1.5880	1.7538	3.0015	2.2621
6	2.5115	2.5440	1.6170	1.9544	3.0276	2.4463
7	2.5812	2.3197	1.5482	2.2197	3.0070	2.2767
8	2.6603	2.5175	1.5143	1.7587	3.1421	2.3732
9	2.6362	2.3863	1.5332	1.8854	3.0231	2.3359
10	2.4749	2.3466	1.4879	1.7319	2.9224	2.4468
11	2.5283	2.3642	1.2359	1.9257	3.0373	2.3063
12	2.5109	2.3338	1.4913	1.7884	3.8817	2.4869
13	2.5618	2.3168	1.4388	1.6702	3.1053	2.1536
14	2.4345	2.4730	1.6598	1.9164	2.9476	2.6872
15	2.5854	2.3797	1.5298	1.6883	3.1432	2.1501
16	2.3685	2.4269	1.6343	1.9960	2.9733	2.5651
SPECTRAL BANDWIDTH IN MICRONS						
	0.07	0.08	0.06	0.14	0.20	0.27

Table C-7a
Landsat-5 Reflective Band Gain and Bias Data

	Band					
Detector	1	2	3	4	5	7
Gain in Counts/(Milliwatt/CM^2-SR)						
1	236.3227	96.0744	152.3627	85.1172	363.9618	585.6809
2	234.6015	95.7134	153.5105	84.7039	359.6590	580.2047
3	237.2970	95.6122	152.0179	84.1867	361.7650	584.8107
4	234.4515	95.6488	153.3537	83.8414	360.5733	581.5428
5	238.0773	95.7841	152.0701	84.5281	362.4290	590.7480
6	233.9485	95.3500	151.6597	84.4484	362.6152	580.6885
7	236.5742	95.5780	149.9075	84.3445	360.2304	588.9999
8	234.5409	96.5793	152.9239	85.0906	366.2844	587.2036
9	234.9727	95.2780	150.6806	83.7922	362.7733	585.9020
10	235.8879	96.0402	152.6582	85.4281	363.2622	584.5619
11	236.5773	96.2585	150.8254	84.3898	365.6318	589.9777
12	236.1636	96.6037	153.4299	84.4516	365.0056	589.1067
13	236.0939	96.0341	151.6015	84.3648	363.0572	589.1885
14	233.6636	95.6476	153.3000	84.8367	360.9742	588.7746
15	235.4091	96.4902	152.4910	84.2047	363.7120	585.0325
16	235.7258	94.8695	153.7612	84.8398	364.5728	586.5492

Table C-7a (Continued)

	Band					
Detector	1	2	3	4	5	7
Bias in Counts						
1	2.2965	2.2691	2.4569	2.6652	3.5727	3.8241
2	1.9313	1.5379	1.9920	2.1440	3.2601	3.2194
3	1.8734	1.8693	1.9709	2.4287	3.2736	3.3549
4	1.8895	1.5357	1.7282	1.9523	3.2701	3.2758
5	1.7628	1.5069	1.8442	2.2046	3.1314	3.1052
6	1.9744	1.8161	1.7437	2.3107	3.2506	3.2558
7	1.7435	1.5605	1.8571	2.6408	3.1252	3.0121
8	2.1147	1.7427	1.8852	2.2091	3.5024	3.2427
9	1.6412	1.7117	2.0105	2.1524	3.2843	3.1006
10	1.8049	1.5873	1.8130	2.0022	3.3784	3.1922
11	1.5761	1.8789	1.8650	2.4152	3.2440	3.1158
12	1.7649	1.6117	1.7688	2.0702	3.2882	3.0190
13	1.6324	1.5945	1.7462	2.1371	3.1520	3.0402
14	1.8487	1.5986	1.8063	2.1669	3.3691	3.2440
15	1.6416	1.6357	1.7881	2.1682	3.1806	3.1068
16	1.8337	1.5766	1.8836	2.1291	3.3460	3.2790
Spectral Bandwidth in Microns						
	0.066	0.082	0.067	0.128	0.217	0.252

Table C-8
Radiometric Range of NASA-TM Output Products

BAND	R_{MIN}*	R_{MAX}*
1	-0.15	15.21
2	-0.28	29.68
3	-0.12	20.43
4	-0.15	20.62
5	-0.037	2.719
7	-0.015	1.438

*UNITS OF MILLIWATTS PER SQUARE CENTIMETER PER STERADIAN PER MICROMETER (I.E., SPECTRAL RADIANCE)

Table C-9
Landsat-4 Calibration Level for Step 1: All Lamps OFF

Detector	Average IC Reference Pulse (P_7^0 [000] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	2.71	2.68	2.61	2.70	2.92	2.84
2	2.20	2.21	2.18	2.22	2.57	2.39
3	2.34	2.28	2.39	2.33	–	2.36
4	1.69	–	2.32	2.22	2.57	2.42
5	2.35	2.12	2.16	2.06	2.69	2.19
6	2.26	2.26	2.22	2.27	2.73	2.44
7	2.28	2.09	2.16	2.06	2.64	2.56
8	2.15	2.20	2.39	2.33	2.84	2.39
9	2.34	2.10	2.19	2.05	2.60	2.31
10	1.85	2.10	2.14	2.04	2.60	2.47
11	2.25	2.17	2.07	2.05	2.63	2.28
12	1.66	2.10	2.12	2.01	2.58	2.35
13	2.19	2.12	2.01	2.04	2.69	2.13
14	2.17	2.16	2.25	2.05	2.59	2.52
15	2.21	2.10	1.99	2.04	2.80	2.15
16	2.25	2.24	2.26	2.04	2.63	2.50

*Reference pulse test of March 20, 1982
–Failed detector

Table C-10
Landsat-4 Calibration Level for Step 2: Lamp A ON

Detector	Average IC Reference Pulse (P_7^0 [000] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	107.69	102.53	90.99	92.12	47.25	61.09
2	104.79	92.95	91.94	96.76	68.07	57.11
3	109.76	100.11	89.71	92.70	–	59.34
4	106.56	–	91.32	97.34	67.93	57.06
5	107.94	101.71	90.13	91.30	45.82	58.97
6	104.48	92.60	92.85	98.21	66.91	56.85
7	107.01	99.46	89.58	91.40	46.05	58.41
8	104.79	91.23	91.58	97.23	67.23	56.43
9	106.39	100.47	89.79	91.87	45.85	59.19
10	105.29	90.47	92.14	101.11	66.55	56.45
11	107.84	99.53	89.03	90.86	46.10	58.88
12	105.62	90.15	92.78	98.30	67.04	57.83
13	108.10	100.37	89.78	92.82	45.87	58.36
14	105.47	91.46	91.56	97.88	66.46	58.08
15	108.89	100.35	90.60	89.84	46.64	59.48
16	104.96	90.15	91.33	96.57	68.25	59.70

*Reference pulse test of March 20, 1982
–Failed detector

Table C-11
Landsat-4 Calibration Level for Step 3: Lamps A and B ON

Detector	Average IC Reference Pulse (P_7^0 [100] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	174.48	180.62	155.73	184.85	87.56	106.21
2	169.00	157.38	160.44	181.46	125.46	110.28
3	178.64	177.00	154.07	185.57	–	103.95
4	170.13	–	159.72	182.28	125.62	110.45
5	175.68	179.49	154.79	183.10	85.77	103.49
6	168.16	156.22	161.91	183.86	123.76	110.07
7	173.85	176.04	153.90	183.26	86.18	103.02
8	167.96	154.04	159.97	182.47	124.25	109.31
9	173.67	177.55	154.65	184.08	85.66	103.88
10	169.03	153.05	160.89	189.43	123.18	109.08
11	175.05	176.01	153.12	182.13	86.23	103.24
12	168.94	152.41	161.79	183.65	123.96	111.73
13	175.89	176.77	154.43	186.13	85.88	102.56
14	169.14	154.57	159.81	183.21	122.85	111.96
15	177.06	177.64	155.55	180.49	87.00	103.83
16	168.91	152.51	159.10	180.90	125.52	114.47

*Reference pulse test of March 20, 1982
-Failed detector

Table C-12
Landsat-4 Calibration Level for Step 4: Lamp B ON

Detector	Average IC Reference Pulse (P_7^0 [010] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	70.42	81.40	68.27	96.56	43.66	48.83
2	65.60	66.63	70.91	87.77	60.54	55.96
3	71.58	79.26	67.14	96.21	–	47.35
4	67.21	–	70.56	87.98	60.37	55.89
5	70.53	80.34	67.35	94.81	42.48	46.98
6	65.64	66.26	71.56	89.00	59.46	55.85
7	69.67	78.67	66.92	95.42	42.53	46.87
8	66.89	65.30	70.66	88.25	59.60	55.36
9	69.46	79.23	67.03	95.64	42.32	47.08
10	66.07	64.70	70.98	91.34	59.09	55.21
11	70.26	78.70	66.45	94.54	42.58	46.87
12	66.70	64.44	71.33	88.75	59.46	56.50
13	70.73	78.61	67.04	96.57	42.41	46.51
14	66.18	65.35	70.55	88.41	58.87	56.66
15	70.92	79.44	67.48	93.67	43.14	47.40
16	65.79	64.21	70.41	87.58	60.54	58.03

*Reference pulse test of March 20, 1982
-Failed detector

Table C-13
Landsat-4 Calibration Level for Step 5: Lamps B and C ON

Detector	Average IC Reference Pulse (P_7^0 [011] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	115.88	127.03	105.64	140.70	66.56	80.75
2	109.45	106.48	111.09	135.10	92.42	88.90
3	118.09	124.15	104.29	141.01	–	78.88
4	110.05	–	110.64	135.87	92.30	88.95
5	116.22	126.09	104.81	138.96	64.86	78.42
6	109.28	106.03	112.32	137.14	91.07	88.65
7	115.37	123.45	104.23	139.48	65.10	78.11
8	108.96	104.33	110.83	136.06	91.41	87.95
9	114.88	124.55	104.67	140.23	64.94	78.85
10	109.35	103.49	111.45	141.03	90.68	87.85
11	116.47	123.51	103.68	138.40	65.23	78.28
12	109.44	103.19	112.08	136.84	91.15	90.03
13	116.90	123.79	104.43	141.78	64.95	77.86
14	109.70	104.47	110.77	136.49	90.50	90.04
15	117.38	124.68	105.31	137.29	66.07	78.93
16	109.48	102.90	110.37	134.80	92.67	92.36

*Reference pulse test of March 20, 1982
-Failed detector

Table C-14
Landsat-4 Calibration Level for Step 6: Lamps A, B, and C ON

Detector	Average IC Reference Pulse (P_7^0 [111] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	219.59	225.38	192.57	226.49	109.72	137.32
2	211.38	196.39	199.73	227.68	156.74	142.16
3	224.37	220.79	190.43	227.93	–	135.04
4	214.33	–	198.57	228.72	157.23	142.98
5	221.09	223.94	191.50	225.09	107.65	134.49
6	210.74	194.99	201.58	230.68	154.82	142.49
7	219.16	219.61	190.35	225.02	108.17	133.76
8	210.77	192.43	198.81	229.24	155.27	141.49
9	218.43	221.51	191.11	226.80	107.56	135.00
10	212.19	191.17	200.44	236.84	154.19	141.22
11	220.93	219.58	189.53	224.08	108.32	134.29
12	212.93	190.52	201.40	230.66	155.32	144.57
13	221.70	220.78	191.18	229.33	107.85	133.38
14	212.11	192.97	199.06	229.98	153.85	144.86
15	223.27	221.53	192.65	222.79	108.83	134.84
16	211.50	190.28	198.27	227.12	156.80	147.78

*Reference pulse test of March 20, 1982
-Failed detector

Table C-15
Landsat-4 Calibration Level for Step 7: Lamps A and C ON

Detector	Average IC Reference Pulse (P_7^0 [101] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	153.06	148.24	128.50	135.88	69.78	92.41
2	148.69	133.10	132.09	143.70	100.07	89.80
3	156.65	145.15	126.91	136.16	–	90.40
4	150.17	–	131.46	144.39	100.00	89.84
5	154.16	147.41	127.63	134.55	68.18	89.84
6	148.24	132.18	133.43	145.53	98.52	89.58
7	152.47	144.44	126.90	134.92	68.55	89.50
8	147.94	130.39	131.62	144.46	98.85	88.91
9	152.23	145.93	127.54	135.57	68.13	90.29
10	148.92	129.57	132.70	150.21	98.05	88.93
11	153.99	144.42	126.30	134.26	68.58	89.91
12	149.02	128.84	133.38	145.49	98.76	91.00
13	154.59	145.64	127.46	136.99	68.28	89.37
14	149.20	130.56	131.85	145.12	97.95	91.25
15	156.82	145.84	128.38	132.70	69.28	90.65
16	148.97	129.03	131.27	143.63	100.21	93.58

*Reference pulse test of March 20, 1982
-Failed detector

Table C-16
Landsat-4 Calibration Level for Step 8: Lamp C ON

Detector	Average IC Reference Pulse (P_7^0 [001] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	48.61	48.53	40.67	47.30	25.73	34.96
2	45.36	42.04	42.38	49.78	34.81	35.42
3	49.27	47.20	39.85	47.17	–	33.80
4	46.65	–	42.10	49.96	34.63	35.31
5	48.47	47.88	39.97	46.35	24.71	33.46
6	45.52	41.91	42.94	50.54	34.26	35.25
7	48.13	46.89	39.65	46.80	24.94	33.39
8	45.80	41.36	42.48	50.06	34.35	35.06
9	47.80	47.24	39.73	46.79	24.73	33.72
10	45.94	40.91	42.62	51.77	33.88	35.07
11	48.37	46.93	39.40	46.31	24.83	33.59
12	46.40	40.80	42.75	50.56	34.24	35.77
13	48.57	47.17	39.81	47.35	24.87	33.19
14	45.93	41.39	42.46	50.44	34.00	36.04
15	48.92	47.38	40.22	45.89	25.27	33.88
16	45.61	40.98	42.35	49.88	34.96	37.01

*Reference pulse test of March 20, 1982
-Failed detector

Table C-17
Landsat-5 Calibration Level for Step 1: All Lamps OFF

Detector	Average IC Reference Pulse (P_7^0 [000] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	2.850	2.446	2.685	2.926	2.647	2.895
2	2.495	1.940	2.122	2.162	2.255	2.335
3	2.395	2.089	2.299	2.210	2.313	2.404
4	2.497	1.946	2.089	2.131	2.300	2.355
5	2.302	1.902	2.155	2.065	2.174	2.266
6	2.586	2.016	2.134	2.136	2.281	2.403
7	2.216	1.967	2.130	2.082	2.215	2.374
8	2.733	2.017	2.182	2.180	2.483	2.395
9	2.185	2.013	2.270	2.110	2.245	2.230
10	2.309	2.005	2.151	2.106	2.386	2.343
11	2.151	1.977	2.125	2.121	2.239	2.248
12	2.317	2.005	2.161	2.110	2.298	2.298
13	2.214	1.963	2.049	2.075	2.165	2.180
14	2.461	2.013	2.146	2.171	2.415	2.493
15	2.147	1.995	2.035	2.078	2.152	2.150
16	2.407	2.025	2.175	2.246	2.354	2.440

*Reference pulse test of August 30, 1983

Table C-18
Landsat-5 Calibration Level for Step 2: Lamp A ON

Detector	Average IC Reference Pulse (P_7^0 [100] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	105.507	92.245	92.445	84.383	30.143	62.143
2	101.368	86.201	73.484	67.475	31.777	59.658
3	104.884	91.531	91.977	82.919	29.138	60.870
4	102.690	87.035	73.080	66.821	31.354	59.511
5	104.981	91.068	92.117	83.361	28.754	61.158
6	102.346	87.659	72.041	67.660	31.607	59.225
7	103.717	91.258	90.995	83.949	28.614	61.012
8	102.499	87.854	72.385	68.169	31.997	59.824
9	102.931	91.037	91.351	82.831	28.765	60.079
10	102.834	87.240	72.378	67.731	31.351	59.177
11	104.621	91.722	91.159	83.522	28.951	60.255
12	101.977	88.163	72.984	67.470	31.444	59.318
13	104.039	91.754	91.789	83.342	28.705	59.047
14	100.864	86.764	72.865	67.956	31.418	59.326
15	105.465	91.877	92.102	83.096	28.942	59.774
16	101.117	86.373	73.860	67.932	31.803	59.601

*Reference pulse test of August 30, 1983

Table C-19
Landsat-5 Calibration Level for Step 3: Lamps A and B ON

Detector	Average IC Reference Pulse (P_7^0 [110] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	187.135	161.921	160.405	153.511	59.665	101.601
2	172.576	143.286	131.511	131.114	59.232	97.967
3	186.102	160.842	160.190	151.158	58.068	100.052
4	174.903	144.723	131.021	130.001	58.901	97.893
5	186.544	160.571	160.575	152.265	57.469	100.626
6	174.033	145.211	128.887	131.201	59.213	97.428
7	184.179	160.832	158.533	152.639	57.113	100.314
8	174.191	145.642	129.615	132.407	59.806	98.331
9	182.743	160.186	159.038	151.355	57.382	98.936
10	175.172	144.796	129.646	131.610	58.984	97.303
11	185.944	161.122	158.835	152.210	57.733	99.120
12	173.637	146.325	130.667	131.095	59.102	97.722
13	184.691	161.733	159.998	152.256	57.332	97.100
14	171.614	143.975	130.543	131.889	58.559	97.374
15	187.465	161.932	160.532	151.691	57.762	97.906
16	172.029	143.289	132.245	131.926	59.668	97.516

*Reference pulse test of August 30, 1983

Table C-20
Landsat-5 Calibration Level for Step 4: Lamp B ON

Detector	Average IC Reference Pulse (P_7^0 [010] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	84.857	72.899	71.218	73.375	32.321	42.953
2	73.819	59.271	60.618	67.016	30.056	40.903
3	83.997	72.145	70.875	72.117	31.232	41.897
4	74.712	59.853	60.341	66.454	29.853	40.829
5	84.194	71.715	71.049	72.577	30.887	41.969
6	74.383	60.329	59.441	67.212	30.100	40.624
7	83.103	71.893	70.163	73.076	30.662	41.850
8	74.519	60.439	59.769	67.647	30.544	41.003
9	82.364	71.737	70.427	72.098	30.895	41.242
10	74.650	59.990	59.783	67.144	29.984	40.530
11	83.677	72.283	70.236	72.570	31.056	41.346
12	74.016	60.645	60.223	66.956	29.995	40.611
13	83.169	72.259	70.696	72.431	30.828	40.462
14	73.294	59.659	60.150	67.387	29.810	40.622
15	84.299	72.424	70.960	72.127	31.108	40.929
16	73.402	59.349	60.957	67.484	30.543	40.766

*Reference pulse test of August 30, 1983

Table C-21
Landsat-5 Calibration Level for Step 5: Lamps B and C ON

Detector	Average IC Reference Pulse (P_7^0 [011] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	143.582	125.526	129.598	116.573	49.016	69.197
2	123.021	102.828	110.510	109.603	46.506	71.675
3	142.523	124.445	129.345	114.877	47.657	67.864
4	124.575	103.875	110.084	108.586	46.185	71.608
5	142.802	124.105	129.819	115.900	47.141	68.150
6	124.127	104.498	108.342	109.741	46.497	71.246
7	140.979	124.357	128.151	116.445	46.803	67.943
8	124.179	104.683	108.955	110.630	47.016	71.857
9	139.662	123.961	128.637	115.234	47.106	67.024
10	124.796	103.975	108.955	110.033	46.310	71.143
11	142.275	124.816	128.506	115.813	47.472	67.161
12	123.726	105.172	109.837	109.554	46.360	71.314
13	141.122	125.170	129.457	115.789	47.057	65.756
14	122.338	103.411	109.821	110.266	45.977	71.201
15	143.343	125.413	129.734	115.462	47.421	66.390
16	122.788	102.907	111.355	110.282	47.040	71.334

*Reference pulse test of August 30, 1983

Table C-22
Landsat-5 Calibration Level for Step 6: Lamps A, B, and C ON

Detector	Average IC Reference Pulse (P_7^0 [111] * in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	235.198	214.067	218.657	196.284	76.114	127.730
2	219.415	186.804	181.064	172.480	75.420	128.661
3	234.707	212.346	218.477	193.448	74.192	126.127
4	221.564	188.588	180.750	171.057	75.049	128.766
5	234.736	212.687	219.199	195.185	73.554	126.741
6	220.865	189.090	177.741	172.629	75.495	128.047
7	233.088	213.073	216.368	195.314	73.092	126.590
8	220.887	189.769	178.507	174.101	76.170	129.381
9	231.860	211.995	217.009	193.987	73.419	124.667
10	221.820	188.821	178.734	173.064	75.233	128.112
11	234.183	213.141	216.839	194.805	73.985	124.897
12	220.256	190.794	180.230	172.401	75.232	128.551
13	233.187	214.195	218.581	195.136	73.304	122.411
14	218.159	187.707	180.071	173.448	74.582	128.107
15	234.635	214.635	219.174	194.459	73.908	123.232
16	218.451	186.807	182.503	173.574	75.897	128.005

*Reference pulse test of August 30, 1983

Table C-23
Landsat-5 Calibration Level for Step 7: Lamps A and C ON

Detector	Average IC Reference Pulse (P_7^0 [101])* in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	163.430	144.407	150.481	127.045	47.040	88.245
2	150.471	129.679	123.272	108.786	47.933	90.312
3	162.473	143.405	150.196	125.174	45.676	86.752
4	152.453	130.908	122.786	107.864	47.598	90.256
5	162.997	143.152	150.670	126.024	45.221	87.171
6	151.815	131.548	120.859	109.069	47.887	89.881
7	160.842	143.462	148.779	126.597	44.854	87.018
8	151.955	131.913	121.478	109.962	48.381	90.699
9	159.531	142.884	149.283	125.385	45.157	85.816
10	152.769	131.160	121.574	109.351	47.709	89.858
11	162.310	143.878	149.113	126.124	45.491	86.098
12	151.411	132.603	122.546	108.810	47.825	90.173
13	161.377	144.290	150.217	126.144	45.122	84.289
14	149.851	130.470	122.448	109.551	47.412	89.953
15	163.744	144.425	150.754	125.727	45.469	85.034
16	150.276	129.791	124.158	109.662	48.315	90.136

*Reference pulse test of August 30, 1983

Table C-24
Landsat-5 Calibration Level for Step 8: Lamp C ON

Detector	Average IC Reference Pulse (P_7^0 [001])* in Digital Counts (DN)					
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
1	61.366	55.207	61.318	46.610	19.469	29.349
2	51.643	45.584	52.182	44.814	18.604	33.221
3	60.625	54.577	60.906	45.638	18.707	28.397
4	52.335	46.043	51.906	44.370	18.505	33.145
5	60.729	54.288	61.115	45.895	18.429	28.447
6	52.208	46.487	51.114	44.982	18.633	33.061
7	59.941	54.386	60.311	46.254	18.333	28.392
8	52.345	46.559	51.433	45.338	18.928	33.356
9	59.417	54.347	60.636	45.745	18.483	27.981
10	52.439	46.240	51.420	44.971	18.631	32.972
11	60.438	54.800	60.525	46.066	18.640	28.061
12	51.956	46.725	51.864	44.789	18.592	33.019
13	60.191	54.757	60.910	45.977	18.452	27.466
14	51.559	46.033	51.879	45.187	18.545	33.092
15	60.951	54.899	61.123	45.868	18.656	27.801
16	51.810	45.788	52.723	45.180	18.913	33.209

*Reference pulse test of August 30, 1983

APPENDIX D

IMPROVED INTERRANGE VECTOR (IIRV) MESSAGE

APPENDIX D

IMPROVED INTERRANGE VECTOR (IIRV) MESSAGE

The IIRV message in Figure D-1 shall be coded in USASCII. All data fields are right justified, with leading zeros added as needed. A positive sign (+) shall be indicated by a blank, and a negative sign (-) shall be indicated by a minus. The IIRV message shall contain spacecraft position and velocity for the given epoch time. Table D-1 contains IIRV message body data field explanations.

Vector epoch times will be provided one time daily at 00:00 hours GMT.

Line 1: __ __ __ __ CR CR LF LF (optional message text)

Line 2: $\underbrace{\text{G I I R V}}_{\text{start of message}}$ A $\underbrace{\text{R R R R}}_{\text{destination routing indicator}}$ CR CR LF LF

Line 3: V S T C $\overset{\text{S I}}{\text{C}}$ $\overset{\text{S I}}{\text{C}}$ $\overset{\text{S I}}{\text{C}}$ $\overset{\text{S I}}{\text{C}}$ B B N N N D O Y H H M M S S S S S C C C CR CR LF LF

Line 4: S X X X X X X X X X X X X S Y Y Y Y Y Y Y Y Y Y Y Y S Z Z Z Z Z Z Z Z Z Z Z Z

C C C CR CR LF LF

Line 5: S $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ $\dot{X}$ S $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ $\dot{Y}$ S $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$ $\dot{Z}$

C C C CR CR LF LF

Line 6: M M M M M M M M A A A A A K K K K S M M $\dot{M}$ $\dot{M}$ $\dot{M}$ $\dot{M}$ $\dot{M}$ C C C CR CR LF LF

Line 7: $\underbrace{\text{I T E R M}}_{\text{end of message}}$ Δ $\underbrace{\text{O O O O}}_{\text{originator routing indicator}}$ CR CR LF LF

Figure D-1. IIRV Message Body Format

Table D-1
IIRV ASCII TTY Message Body Explanation

Line	Characters	Explanation
1	- - - - -	Optional message text.
2	GIIRV	Start of message (fixed).
	A	Alphabetic character indicating originator of message: blank = GSFC Z = WLPS E = ETR L = JPL W = WTR J = JSC P = PMR A = AFSCF K = KMR
	RRRR	Destination routing indicator. Specifies the site for which the message was generated. If for more than one station, this field should contain "MANY". Bldg 28 = GLND
3	V (Not Used)	Vector type: 1 = Free flight (routine). 2 = Forced (special update). 3 = Forced (no burn). 4 = Maneuver ignition. 5 = Maneuver cutoff. 6 = Reentry. 7 = Powered flight. 8 = Spare. 9 = Spare.
	s (Not Used)	Source of data: 1 Nominal/planning. 2 Real-time. 3 Off-line. 4 Off-line/mean.
	T (Always 1)	Transfer type: 1 Interrange. 2 Intercenter.
	C (Always 1)	Coordinate system: 1 Geocentric Greenwich Rotation. (All interrange vectors) 2 Aries mean of 1950. (All intercenter vectors)
	SIC (4 characters)	Support Identification Code. Landsat-4 = 1294, Landsat-5 = 1419
	BB (Always 01)	Body number/VID (00-99).

Table D-1 (Continued)

Line	Characters	Explanation
3 (cont)	NNN	Counter number indicating vector transfer number on a per station per transmission basis.
	DOY	Day of year.
	HHMMSSSSS	Vector epoch in GMT with resolution to nearest millisecond.
	CCC	Checksum of preceding characters: 0 through 9 = Face value Minus (-) = 1 Plus (+) = 0
4	S	Sign character: (Minus: - Plus : blank)
	XXXXXXXXXXXX	X component of position (meters).
	YYYYYYYYYYYY	Y component of position (meters).
	ZZZZZZZZZZZZ	Z component of position (meters).
	CCC	Checksum of previous characters: 0 through 9 = Face value. Minus (-) = 1. Plus (+) = 0.
5	S	Sign character.
	$\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}\dot{X}$	X-velocity component.
	$\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}\dot{Y}$	Y-velocity component.
	$\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}\dot{Z}$	Z-velocity component. Note All velocity components are in meters/second with resolution to nearest 1/1000 meter/second.
	CCC	Checksum of preceding characters: 0 through 9 = Face value. Minus (-) = 1. Plus (+) = 0.

Table D-1 (Continued)

Line	Characters	Explanation
6	MMMMMMMM	Mass of target (kilograms with resolution to 1/10 of kilogram) for intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	AAAAA	Average target cross-sectional area (meters squared with resolution to nearest square centimeter) for intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	KKKK	Drag factor (dimensionless)(two digits to left of decimal point). For intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	S	Sign character for mean motion rate. Positive sign denoted by a space or blank. Negative denoted by minus sign.
	$\dot{M}\dot{M}\dot{M}\dot{M}\dot{M}\dot{M}\dot{M}$	Mean motion rate (revolutions/day) no digits to left of decimal point. Primarily intended for GSFC off-line support. Contains all zeroes when not used.
	CCC	Checksum of preceding characters: 0 through 9 = Face value. Minus (-) = 1 Plus (+) = 0
7	ITERM	End of message.
	0000	Originator routing indicator.

APPENDIX E

TM MIDSCAN CORRECTION SUMMARY

APPENDIX E

TM MIDSCAN CORRECTION SUMMARY

This appendix explains how a parabola is added to a smoothed profile polynomial to create a ground calibrated profile polynomial. This is a simplified algorithm that does not include effects from spacecraft attitude deviations. Referring to Figure E-1, the upper curve illustrates an original smoothed profile that is normalized from the ideal scan time of 60743 μseconds to the actual scan time for scan "i." Its value at the time the midscan pulse occurs (T_{FH}) is defined as the profile (reference) offset angle ϕ_{foi}. The second figure illustrates the actual profile for scan "i" in relation to the smoothed profile. The offset angle ϕ_{fi} is found from the first and second half scan times (T_{FH} and T_{SH}) as shown in Figure E-4. The "ith" scan differs from the smoothed profile by a parabola where the midscan amplitude is $(\phi_{fi} - \phi_{oi}) = \Delta_{fi}$. The calculation is performed at time T_{FH}, where T_{FH} is the time of the first half scan. The lowest figure illustrates the original smoothed profile, the parabola, $\Delta(t)$, and the ground calibrated profile that is the parabola added to the original profile.

Figure E-2 gives the profile polynomial modification e uations. The initial forward profile is a fifth-order polynomial with coefficients a_0 through a_5 (b_o through b_5 for reverse scans) defined for the ideal scan time. This initial profile is first adjusted to the actual scan time. The parabola for scan "i" is a second-order polynomial consisting of two terms, $a'_{1,i}$ and $a'_{2,i}$. The ground-calibrated profile is defined as the adjusted fifth-order power series with:

$$a_{1,i} = a_1 \left(\frac{t_I}{t_s}\right) + a'_{1,i} \text{ and } a_{2,i} = a_2 \left(\frac{t_I}{t_s}\right)^2 + a'_{2,i}.$$

The line length code, illustrated in Figure E-3, contains first-half and second-half scan errors E1 and E2, which are defined as R1-T1 and R2-T2, respectively, where R and T represent references and half-scan times. On forward scans, R1 equals 30371.4 μsec and R2 equals 30371.6 μsec and on reverse scans, R_1 = 30371.6 μsec and R_2 = 30371.4 μsec. (In either direction, they total the ideal scan time, t_I = 60743.0 μsec). Firsthalf scan error (FHSERR) and second-half scan error (SHSERR) have the units of 5 MHz clock periods (0.18845 μsec).

These represent the errors (in clock counts) from the references in clock counts (161164 and 161165), and negative values are transmitted in binary 2's complement format as indicated. It should be noted that the midscan pulse is slightly offset from true midscan, and that the first-half and second-half scan errors (E_1 and E_2) will <u>not</u> be zero for a nominal scan (i.e., which requires

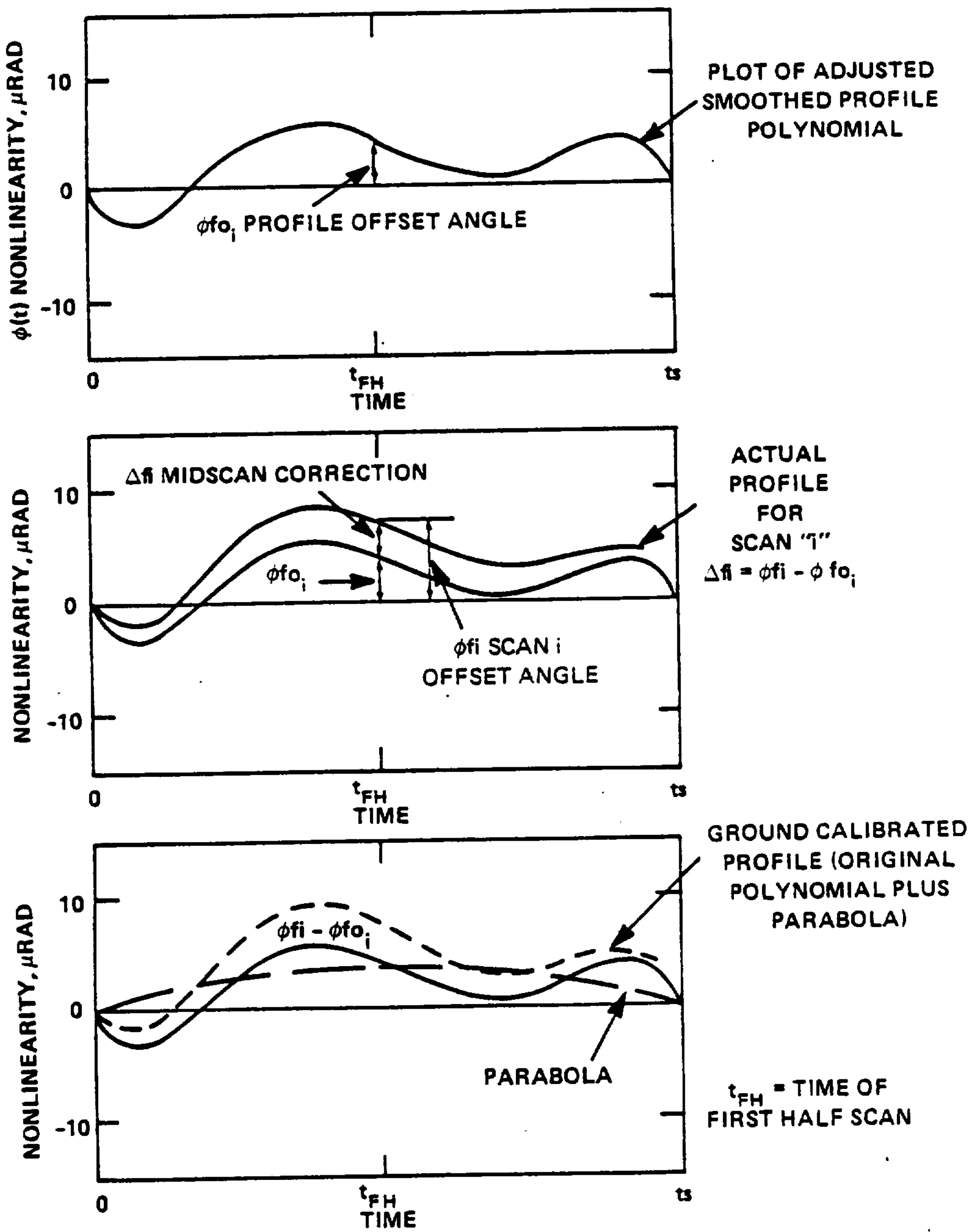


Figure E-1. Profile Polynomial Modification Curves

- INITIAL SMOOTHED PROFILE POLYNOMIAL

  For Ideal Scan Time, $t_I = 0.060743$ Seconds

  $$\phi(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \text{ (for reverse scans use } b_0 \rightarrow b_5\text{)}$$

- ADJUSTED SMOOTH PROFILE POLYNOMIAL

  For Actual Scan Time t_s:

  $$\theta A(t) = a_0 + a_1\left(\frac{t_I}{t_S}\right)t + a_2\left(\frac{t_I}{t_S}\right)^2 t^2 + a_3\left(\frac{t_I}{t_S}\right)^3 t^3 + a_4\left(\frac{t_I}{t_S}\right)^4 t^4 + a_5\left(\frac{t_I}{t_S}\right)^5 t^5$$

- PARABOLA ASSOCIATED WITH LATER SCAN "i",

  t_{FH} = First Half Scan Time for Scan "i"

  $$\Delta(t) = \frac{\Delta fi}{t_{FH}(1-t_{FH}/t_s)}\, t - \frac{\Delta fi}{t_s t_{FH}(1-t_{FH}/t_s)}\, t^2$$

- GROUND CALIBRATED PROFILE POLYNOMIAL:

  $$a_{0,j} = a_0 \qquad a_{3,j} = a_3\left(\frac{t_I}{t_S}\right)^3$$

  $$a_{1,j} = a_1\left(\frac{t_I}{t_S}\right) + \left(\frac{\Delta fi}{t_{FH}(1-t_{FH}/t_s)}\right) \qquad a_{4,j} = a_4\left(\frac{t_I}{t_S}\right)^4$$

  $$a_{2,j} = a_2\left(\frac{t_I}{t_S}\right)^2 - \left(\frac{\Delta fi}{t_s t_{FH}(1-t_{FH}/t_s)}\right) \qquad a_{5,j} = a_5\left(\frac{t_I}{t_S}\right)^5$$

- Δ_{fi} IS OBTAINED FROM LINE LENGTH CODE

Figure E-2. Profile Polynomial Modification Equations

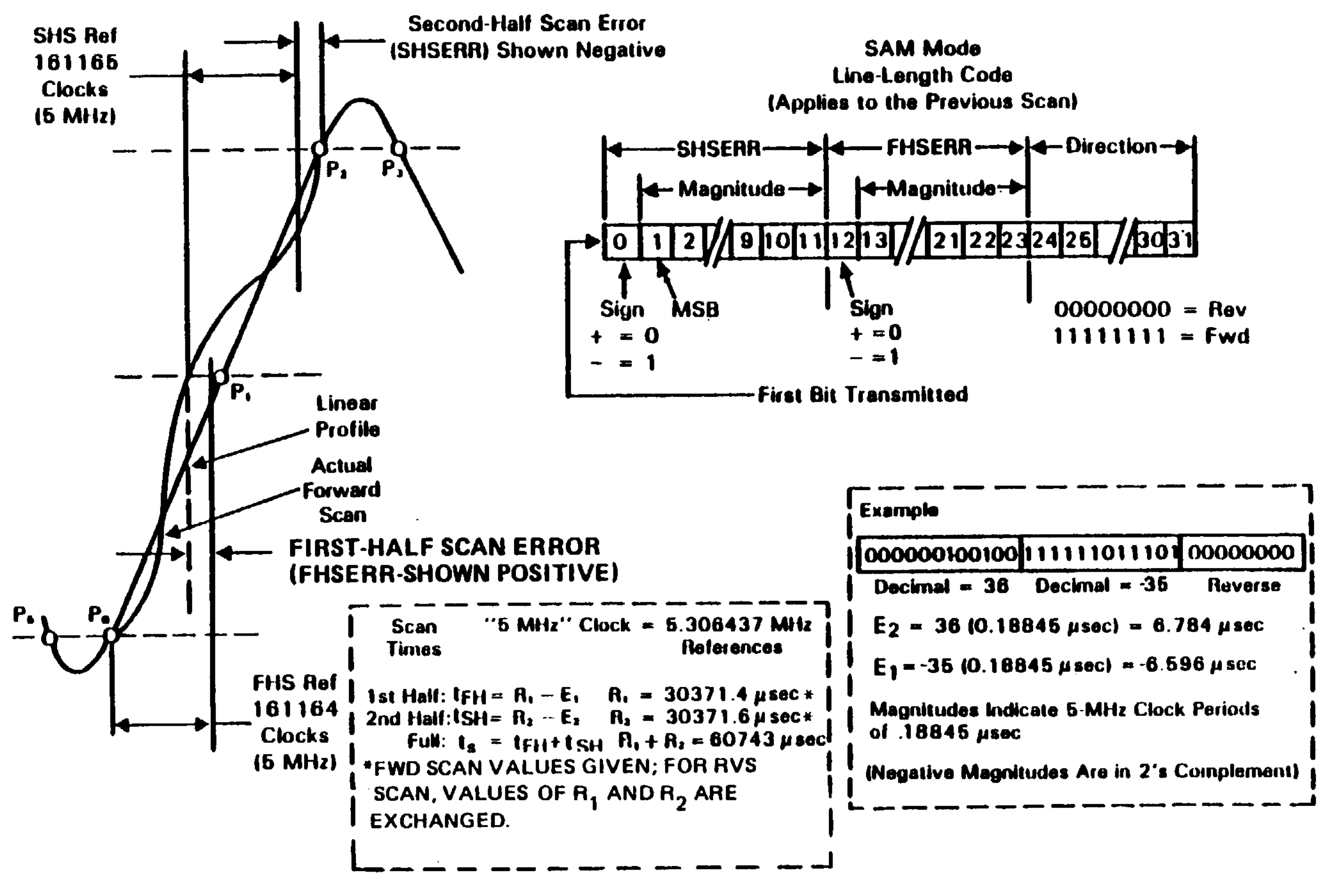


Figure E-3. Line-Length Coding (SAM Mode) no midscan correction). Note the example of decoding shown in Figure E-3, wherein midscan time errors E1 and E2 are found, after which first- and second-half scan time T1 and T2 can be determined.

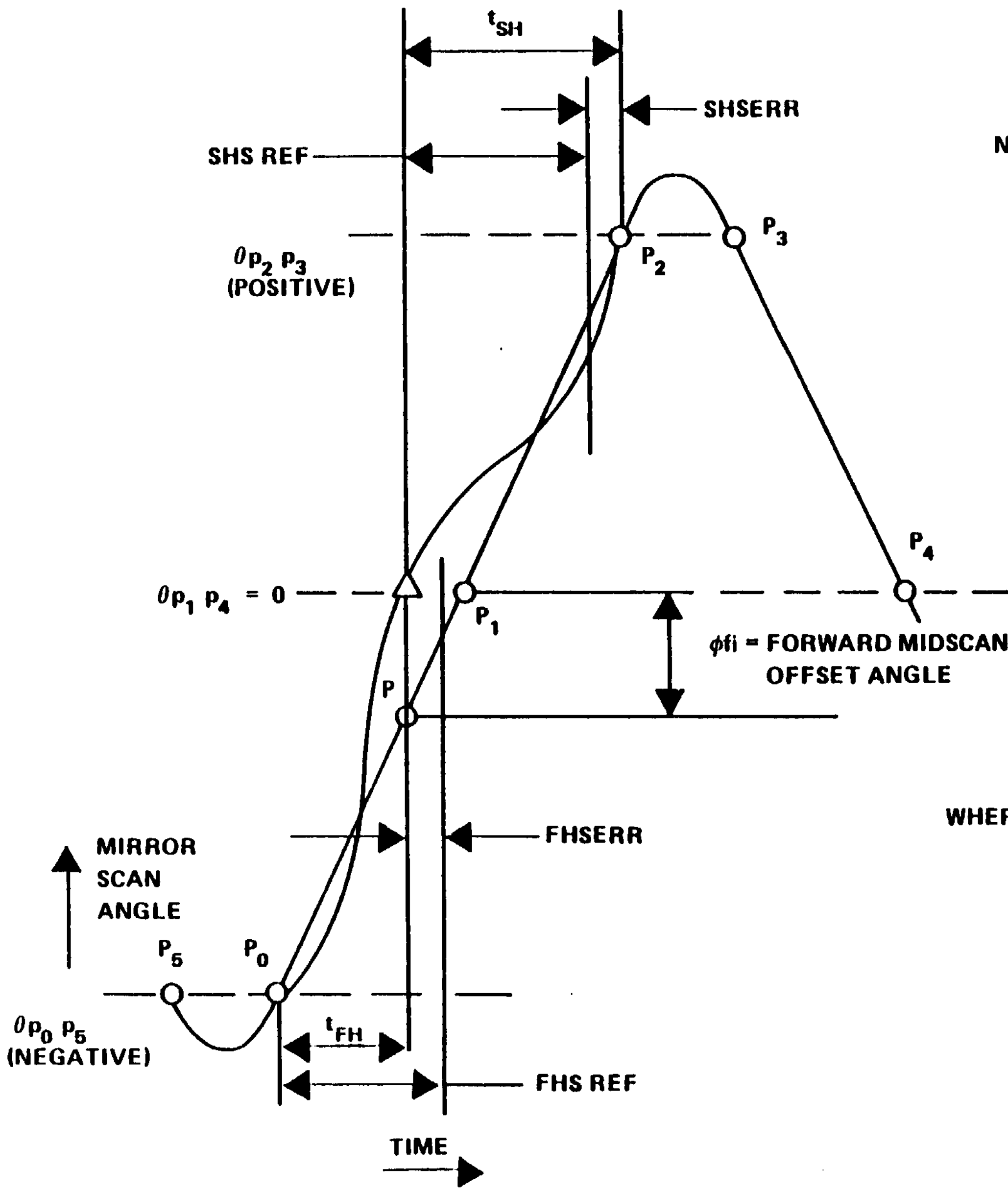
As shown in Figure E-4, when the actual wing mirror proportionality constant K_0 and first- and second-half scan times are taken into account, the midscan offset angle ϕ_{fi} is as indicated. Finally, $\Delta_{fi} = \phi_{fi} - \phi_{foi}$, where ϕ_{foi} is calculated from the adjusted smoothed profile (Figure E-1). Δ_{fi} can then be applied (Figure E-2) to the original smoothed profile polynomial to obtain the desired ground-calibrated forward scan polynomial.

Similar computations yield the reverse midscan correction $\Delta_{ri} = \phi_{roi} - \phi_{ri}$, from which the ground calibrated reverse scan polynomial is obtained. Note the polarity reversal between Δ_{fi} and Δ_{ri}.

For both forward and reverse scans, positive ground calibrated profile indicates positive rotation of the scan mirror relative to the X-axis of the TM optical axis coordinate system. The mirror scanning motion is positive for a forward scan and negative for a reverse scan. Therefore, a positive ground calibrated profile indicates that the mirror has progressed further than the linear scan profile indicates on a forward scan or that the mirror has returned less than the linear scan profile indicates on a reverse scan.

The ground calibrated scan profile, normalized to the nominal scan time (60.743 μsec), varies slowly and requires changing no more often than every 400 scans. The maximum expected ϕ_{fi}/ϕ_{ri} is 100 μradian. Significant active scan time variation (from the ideal 60743 μseconds) can be expected, especially when the MSS and TM instruments operate simultaneously.

Spacecraft attitude errors have the effect of moving the points P_0 through P_5 in inertial space. The effects of these angular motions can be compensated by using the outputs of Angular Displacement Sensors and the Attitude Control Gyros.



NOTE:

ANGLE $\theta p_0 p_5$ IS THE NEGATIVE OF THE START TO MID SCAN ANGLE DEFINED IN TABLE C-1 OR C-1A OF APPENDIX C.

ANGLE $\theta p_2 p_3$ IS THE MID TO END SCAN ANGLE DEFINED IN TABLE C-1 OR C-1A OF APPENDIX C.

1. TAKING INTO ACCOUNT ACTIVE SCAN TIME (t_s) AND SAM WING MIRROR RATIO (K_0)

$$\phi fi = [t_{FH}(K_0 - 1) + t_{SH}(K_0)] \left[\frac{\theta p_2 p_3 - \theta p_0 p_5}{t_s} \right]$$

WHERE $$K_0 = \frac{-\theta p_0 p_5}{\theta p_2 p_3 - \theta p_0 p_5}$$

2. MIDSCAN CORRECTION, SCAN i

$\Delta fi = \phi fi - \phi fo_i$ FOR FORWARD SCANS;

$\Delta ri = \phi ro_i - \phi ri$ FOR REVERSE SCANS

Figure E-4. Forward Offset Angle

APPENDIX F

ALIGNMENT

APPENDIX F

ALIGNMENT

Figure F-1 shows the spacecraft coordinate system. Nominally all subsystems are aligned with the spacecraft coordinate system. The misalignment between the attitude control system, attitude sensors and the TM and the MSS instruments are defined in this appendix. The definition of the TM optical axis is given in Figure F-2. The MSS optical axis is similarly defined as:

Z-axis--The middle of the fiber optics face plate projected through the scan mirror. The scan mirror is at its one-half scan position.

X-axis--Along the scan mirror pivot axis in the nominal direction of spacecraft flight.

Y-axis--Completes the right-hand rule.

The other axes of interest are the ADSA and DRIRU sensing axes and the attitude control reference axes. Attitude quaternion estimates and gyro drift estimates are defined in terms of the attitude control reference axes.

Tables F-1 and F-1a give rotational matrices needed to convert from the DRIRU axes to the attitude control reference axes; from the attitude control reference axes to the TM optical and MSS optical axes; and from the ADSA axes to the TM optical axes. The coordinate transformations given in Tables F-1 and F-1a are based upon prelaunch measurements.

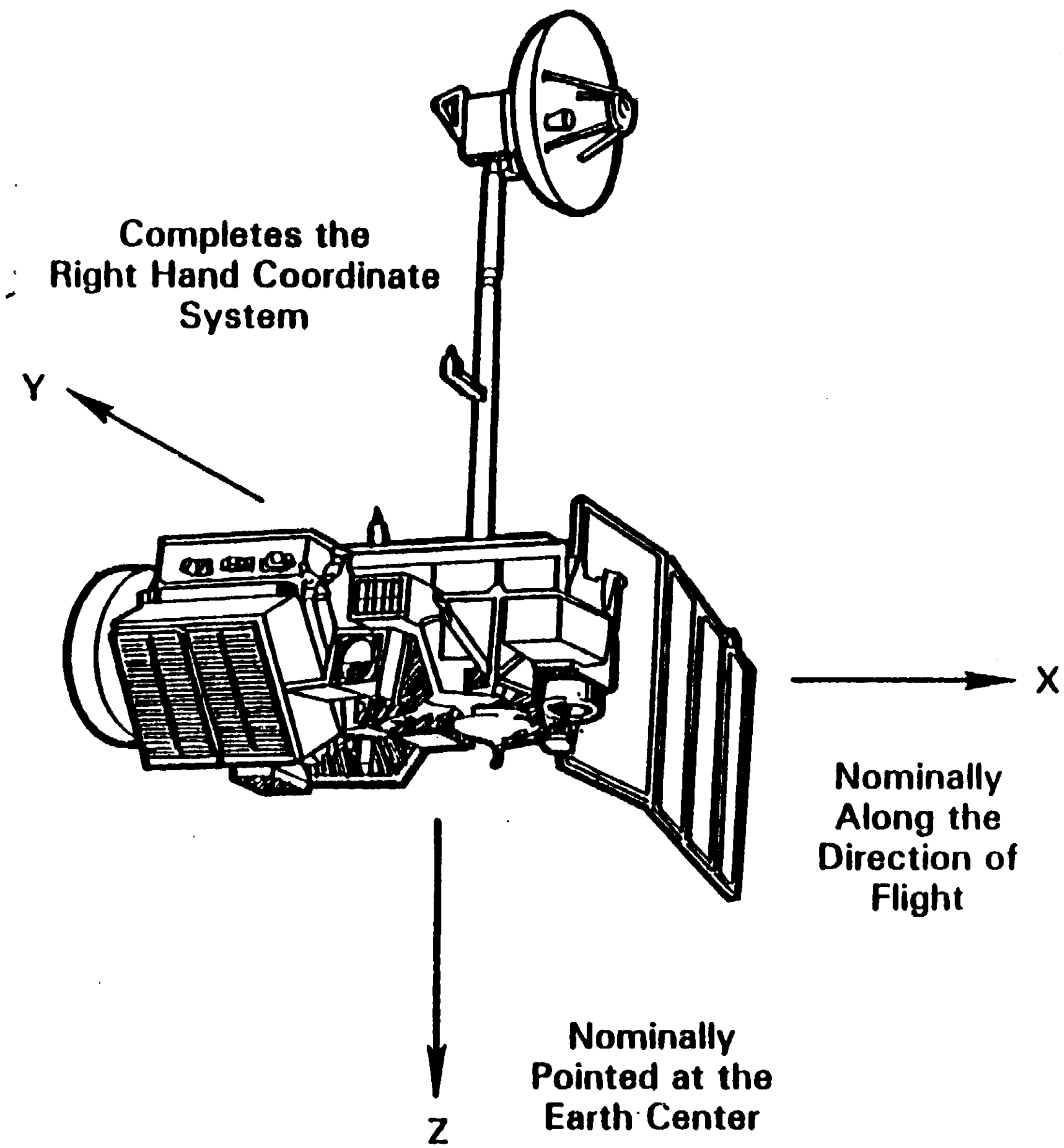


Figure F-1. Landsat Coordinate System

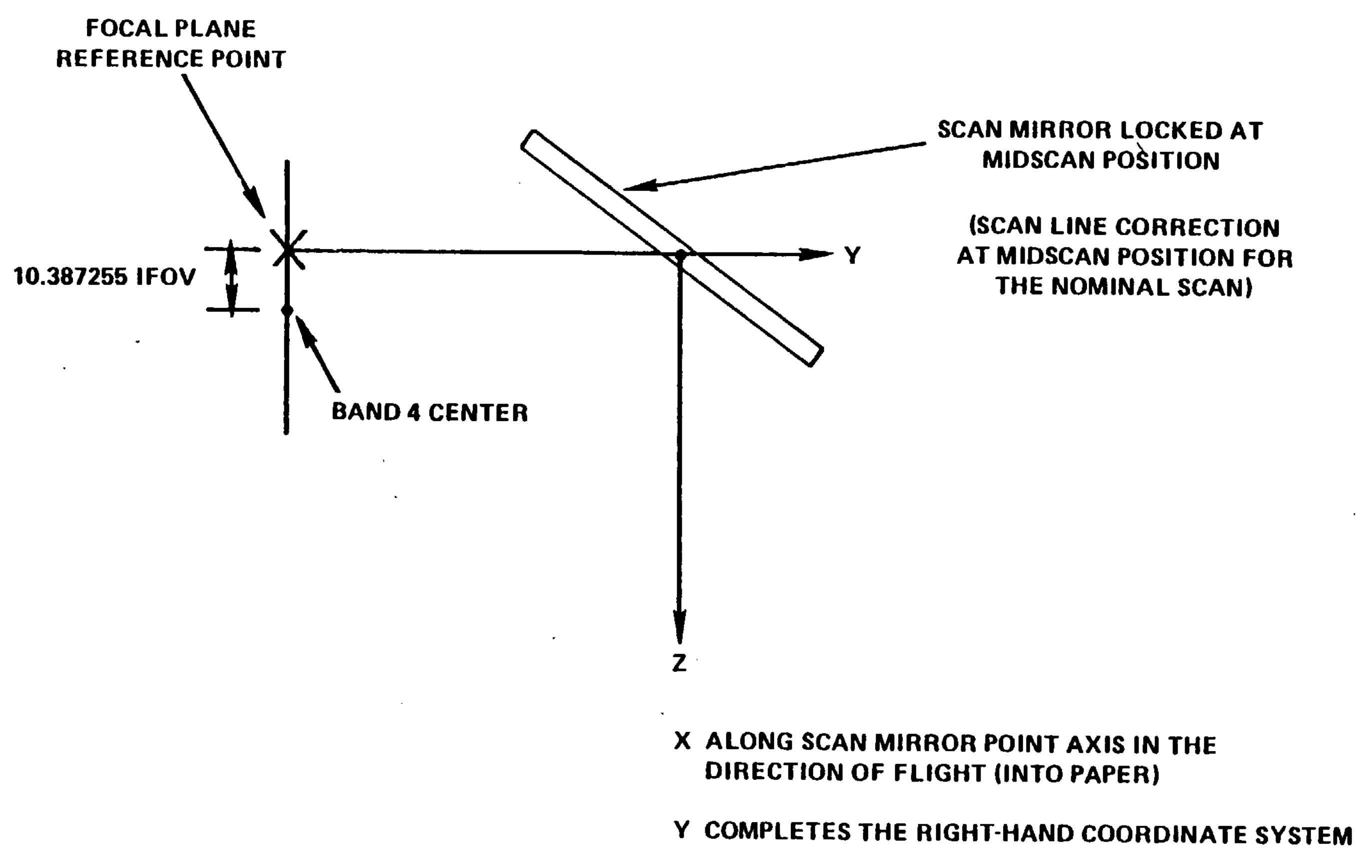


Figure F-2. TM Optical Axis Definition

Table F-1
Landsat-4 Coordinate Transformations

$$\begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix} = \begin{bmatrix} 0.99999990 & 0.151127E\text{-}3 & 0.411108E\text{-}3 \\ -0.15111E\text{-}3 & 0.99999991 & -0.38839E\text{-}3 \\ -0.41114E\text{-}3 & 0.38833E\text{-}3 & 0.99999984 \end{bmatrix} * \begin{bmatrix} X_D \\ Y_D \\ Z_D \end{bmatrix}$$

ATTITUDE CONTROL REFERENCE AXES — DRIRU AXES

$$\begin{bmatrix} X_M \\ Y_M \\ Z_M \end{bmatrix} = \begin{bmatrix} 1.0 & -0.049E\text{-}3 & -1.397E\text{-}3 \\ 0.049E\text{-}3 & 1.0 & 0.232E\text{-}3 \\ 1.397E\text{-}3 & -0.232E\text{-}3 & 1.0 \end{bmatrix} * \begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix}$$

MSS OPTICAL AXES — ATTITUDE CONTROL REFERENCE AXES

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} 1.0 & -0.596E\text{-}3 & 1.464E\text{-}3 \\ 0.596E\text{-}3 & 1.0 & 0.431E\text{-}3 \\ -1.464E\text{-}3 & -0.431E\text{-}3 & 1.0 \end{bmatrix} * \begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix}$$

TM OPTICAL AXES — ATTITUDE CONTROL REFERENCE AXES

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} 1.0 & 3.09E\text{-}4 & -4.79E\text{-}4 \\ 3.48E\text{-}4 & 0.9407 & -0.339646 \\ 5.97E\text{-}4 & 0.339214 & 0.940574 \end{bmatrix} * \begin{bmatrix} X_{ADS} \\ Y_{ADS} \\ Z_{ADS} \end{bmatrix}$$

TM OPTICAL AXES — ADSA AXES

NOTE: THIS TRANSFORM IS NONORTHOGONAL AND CORRECTLY REPRESENTS ADSA SENSING AXIS ORIENTATION.

Table F-1a
Landsat-5 Coordinate Transformations

$$\begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix} = \begin{bmatrix} 1.0 & +8.9880E\text{-}5 & +1.7320E\text{-}5 \\ +5.8319E\text{-}4 & 0.9999998 & +7.7871E\text{-}4 \\ -1.5694E\text{-}4 & -5.1692E\text{-}4 & 0.9999998 \end{bmatrix} * \begin{bmatrix} X_D \\ Y_D \\ Z_D \end{bmatrix}$$

ATTITUDE CONTROL REFERENCE AXES — DRIRU AXES

$$\begin{bmatrix} X_M \\ Y_M \\ Z_M \end{bmatrix} = \begin{bmatrix} 1.0 & -0.000887 & +0.002060 \\ +0.000887 & 1.0 & -0.000819 \\ -0.002060 & +0.000819 & 1.0 \end{bmatrix} * \begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix}$$

MSS OPTICAL AXES — ATTITUDE CONTROL REFERENCE AXES

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} 1.0 & -5.6200E\text{-}4 & -1.3960E\text{-}3 \\ +5.6200E\text{-}4 & 1.0 & +3.8900E\text{-}4 \\ +1.3960E\text{-}3 & -3.8900E\text{-}4 & 1.0 \end{bmatrix} * \begin{bmatrix} X_{ACS} \\ Y_{ACS} \\ Z_{ACS} \end{bmatrix}$$

TM OPTICAL AXES — ATTITUDE CONTROL REFERENCE AXES

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} 1.0 & 0.0 & 0.0 \\ 0.0 & +9.396926E\text{-}1 & -3.420201E\text{-}1 \\ 0.0 & +3.420201E\text{-}1 & +9.396926E\text{-}1 \end{bmatrix} * \begin{bmatrix} X_{ADS} \\ Y_{ADS} \\ Z_{ADS} \end{bmatrix}$$

TM OPTICAL AXES — ADSA AXES

APPENDIX G

TM THERMAL BAND RADIOMETRIC CALIBRATION

APPENDIX G

TM THERMAL BAND RADIOMETRIC CALIBRATION

The radiometric calibration procedure currently planned by NASA for TM Band 6 calibration is described below:

- Definitions

  CB = Average counts of the blackbody calibration data
  CS = Average counts of the shutter flag data
  NB = Effective spectral radiance of the blackbody
  NS = Effective spectral radiance of the shutter flag

- Effective spectral radiance is the equivalent spectral radiance ($mW/cm^2/ster/micron$), uniform across the band, that would give the same TM response. It includes the spectral filter and detector spectral responses.

  For Landsat-4, at 90° K focal plane temperature
  N = (5.4656e-5*T-1.916e-2)* T + 1.771
  Where, T is temperature in degrees Kelvin

  For Landsat-5, at 90° K focal plane temperature
  N = (5.1292e-5*T-1.7651e-2)* T + 1.6023
  Where, T is temperature in degrees Kelvin

- Temperature of blackbody and shutter flag are in payload correction data telemetry.

- Determination of CB = Average of blackbody calibration data (Hughes algorithm)

  - Find the location of the peak blackbody count.

  - Find the pulse shoulders on both sides of the peak that are 95 percent of the peak.

  - Take the center value between the 95 percent shoulders and 3 values on each side of the center value. Average the 7 values to determine the scan average.

  - Average the scan averages.

- Blackbody gain function

  FBB = (CB-CS)/(NB-NS)

- Detector gain estimate

  Gain = a * FBB (Counts/($mW/cm^2/ster/micron$)

Where for Landsat-4, a = 0.71 for detector 1
= 0.725 for detector 2
= 0.71 for detector 3
= 0.72 for detector 4

and for Landsat-5, a = 0.69 for detector 1
= 0.65 for detector 2
= 0.69 for detector 3
= 0.64 for detector 4

- Detector bias estimate

  Bias = CS-(b*NS-c) * FBB (counts)

  Where for Landsat-4, b = 0.9, c = 0.19 for all detectors,

  and for Landsat-5 b = 0.841, c = 0.1702 for detector 1
  b = 0.841, c = 0.2050 for detector 2
  b = 0.831, c = 0.1646 for detector 3
  b = 0.829, c = 0.2030 for detector 4

  Includes effects of internal TM radiators

- Radiometric range of NASA TM output products

  - Digital count 0=200°K
  - Digital count 255=340°K
  - Scaled linearly in range

APPENDIX H

COMMUNICATION LINKS TO FOREIGN GROUND STATIONS

APPENDIX H

COMMUNICATION LINKS TO FOREIGN GROUND STATIONS

H1. GENERAL

The communication links to foreign ground stations from the Landsat FS are:

- S-band transponder telemetry data downlink
- S-band image data (MSS) direct readout downlink
- X-band image data (TM and/or MSS) direct readout downlink

The characteristics of these communication links are summarized in Figure H-1. Each link will provide the functional capability defined in this appendix when a line-of-sight exists between the FS and a receiving ground station. A line-of-sight is assumed to exist for all links defined in this appendix when a line between the FS and a ground station clears any masking obstacle by an angle of 5 degrees for ground station receiving antennas, and by an angle of 0 degrees for the Landsat FS antennas.

H2. COMMUNICATION AND TRACKING

H2.1 PERFORMANCE REQUIREMENTS

The maximum received information bit error probability for the digital telemetry channel at the receiving ground station will be 10^{-5}. The maximum received information bit error probability for digital image data channels at the receiving ground station will be 10^{-5} for MSS image data transmitted via S-band or X-band, and 10^{-6} for TM data transmitted via X-band. The communication and tracking performance requirements of these communication links are based on the presumption that the Landsat FS and the ground stations each perform in accordance with the system performance parameters defined for them in this appendix.

H3. S-BAND TRANSPONDER DOWNLINK

The S-band transponder downlink shall be used to transmit real-time telemetry data from the Landsat FS to the FGS in the mission format at a frequency of 2287.5 MHz. In addition, transmitter baseband modulations may be used for transmitting to GSTDN stations (simultaneously with real-time telemetry) a readout of PCD, a dump of the memory registers in the OBC, a playback of the STR containing previously recorded telemetry data, and/or transmission of ranging tones in the coherent turnaround mode. The transmission equipment configuration for this link is shown in Figure H-2.

For this link, real-time telemetry data in the mission format shall be provided as an NRZ-L input to the transmission equipment. This data shall be converted into Biphase-Space (Biφ-S) format,

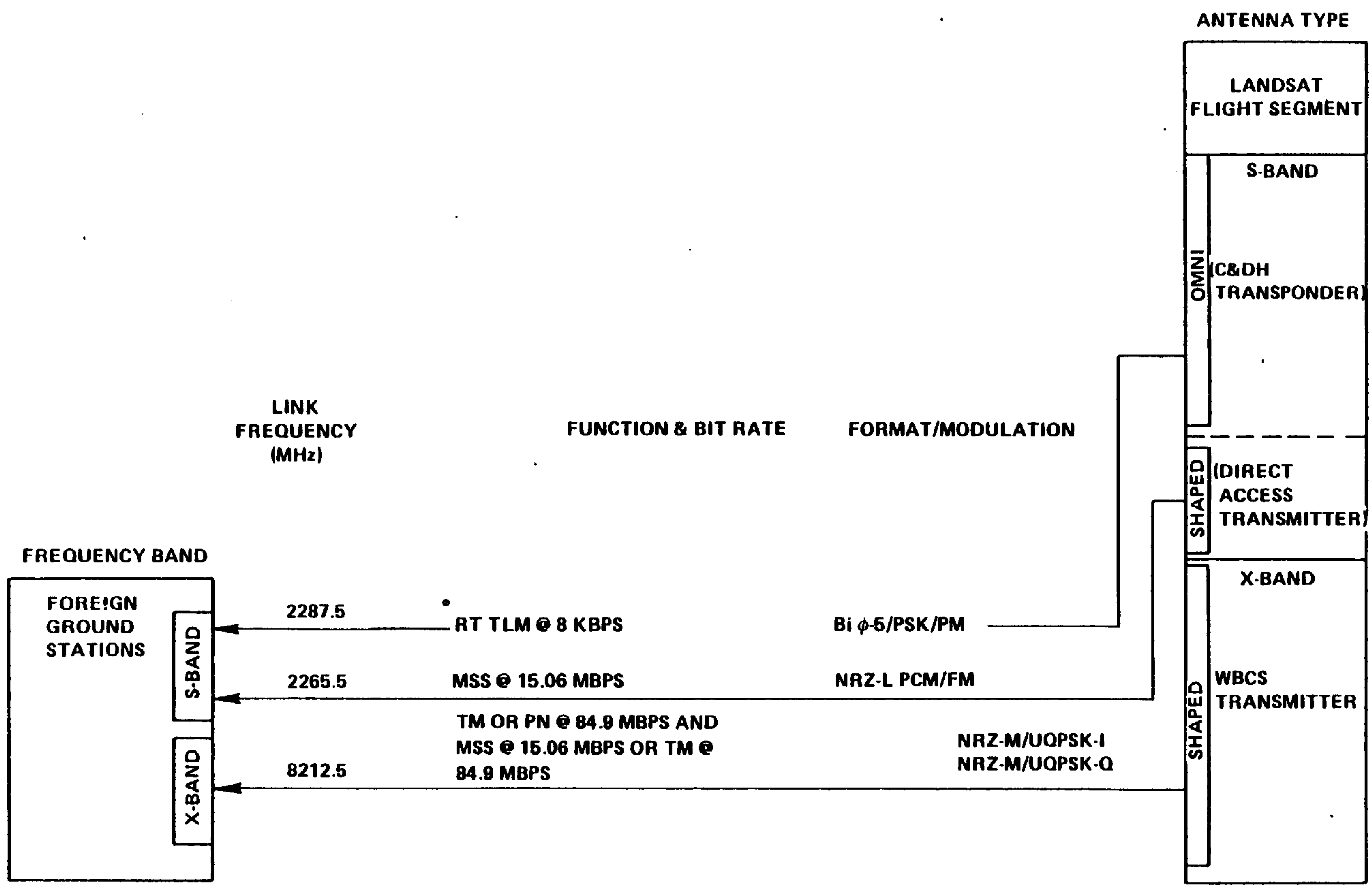


Figure H-1. Summary of Characteristics of RF Communication Links

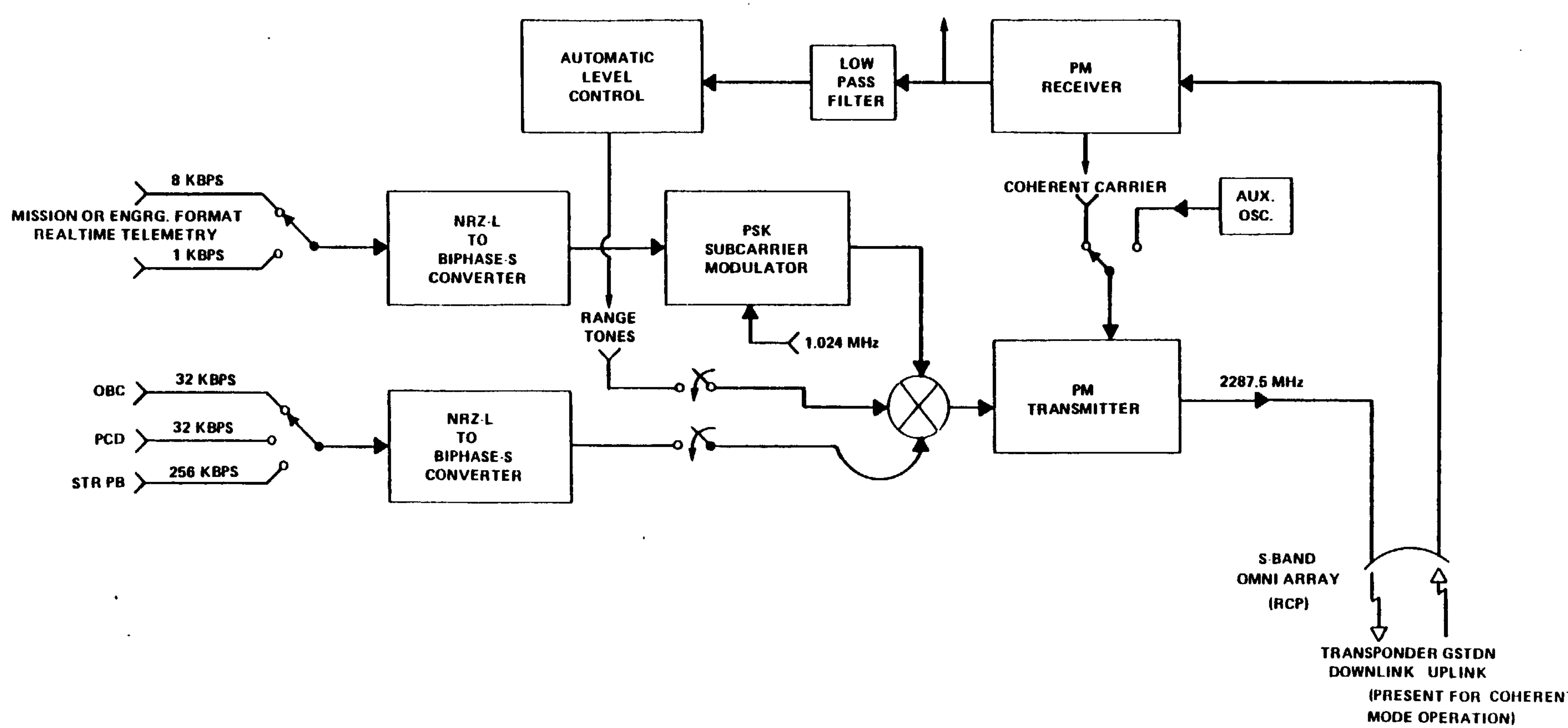


Figure H-2. Landsat FS to FGS S-band Transponder Downlink Configuration which shall then PSK-modulate a downlink subcarrier. In order to support FS operation using GSTDN stations, high-rate data relative to various FS functions or range measurement tones may be transmitted simultaneously with the real-time telemetry over this downlink. High-rate channel data may be either a dump of the memory in the OBC or data used for correcting instrument outputs (i.e., PCD), or a playback from the STR's of telemetry data recorded at an earlier time. High-rate data shall also be provided as an NRZ-L input, and converted to Biϕ-S format. Range tones shall be obtained from the GSTDN uplink channel receiver as analog signal inputs. The selected high-rate channel data and/or ranging tones are added to the real-time telemetry subcarrier, and the output from the summation shall be used to phase-modulate the transponder transmitter. The frequency of this transmitter shall be controlled either by a coherent carrier signal from the uplink receiver or by an auxiliary oscillator. The transponder downlink signal shall be transmitted through the Landsat FS omni antennas.

NASA standard transponder JPL STD 336-M04-TD, located in the C&DH module of the Landsat FS, shall be used as the data transmitter for this link. The nominal output frequency of the transmitter shall be 2287.5 MHz when operating in the noncoherent mode. In the coherent mode, the output frequency shall be 240/221 X the received uplink frequency, which shall be transmitted by GSTDN at 2106.4063 MHz. The RF carrier phase shall be proportional to the linear sum of one or two continuous analog signal waveforms (telemetry subcarrier or range tone) and a high-rate Biϕ-S signal, with a carrier peak-to-peak phase shift other than Pi radians. The phase-modulated carrier shall have a residual carrier frequency component to which the receiver carrier tracking loop locks to obtain a reference carrier for coherent demodulation. Downlink carrier modulation indices shall be:

Modulation Component	Peak Carrier Phase Modulation (Radians)
1.024 MHz real-time Tlm Subcarrier, or	1.6 $\pm$5% (sinusoid)
1.024 MHz real-time Tlm Subcarrier, and	0.8 $\pm$5% (sinusoid)
32 or 256 kbps Biϕ-S and/or	1.0 $\pm$5% (rectangular)
Turnaround ranging signal	$\frac{0.6}{\sqrt{2}}$ RMS $\pm$5% (e.g., 0.6 $\pm$5% one tone)

The telemetry subcarrier shall be PSK-modulated with the 8 kbps real-time telemetry data. The subcarrier shall be phase shifted between $\pm$Pi/2 radians as the modulating bilevel Biϕ-S signal shifts between one level and the other.

The characteristics of the S-band transponder downlink interface are tabulated in Table H-1, and corresponding link margin calculations are provided in Table H-2. Characteristics of the +Z axis (i.e., downward-pointing) omni antenna are summarized in H6.

H4. S-BAND DIRECT READOUT LINK

The S-band direct readout link to the FGS from the Landsat FS shall be used to transmit real-time MSS data from the Landsat FS. The FS equipment configuration for the communication link is shown in Figure H-3.

The MSS on the Landsat FS shall be configured to provide scene data in NRZ-L format. This data shall be reclocked in the S-band direct readout transmitter by a clock signal which is also supplied by the MSS. The reclocked NRZ-L PCM MSS data waveform shall frequency-modulate the S-band transmitter output signal. The antenna on the FS used for this link shall be the shaped S-band unit. At receiving ground stations, the data frequency will be subject to a slight shift ($\leq \pm 0.002$ percent) from that transmitted because of Doppler shift effects.

Salient characteristics of the S-band direct readout link transmitter are listed in Table H-3. The modulation signal input to the transmitter shall be a filtered 15.062 Mbps NRZ-L PCM waveform by which the transmitter frequency shall be deviated ±5.6 MHz (±5 percent) about the nominal carrier frequency of 2265.5 MHz. Negative frequency deviation shall correspond to a logic "zero" and positive frequency deviation shall represent a logic "one." The instantaneous RF carrier frequency deviation from the nominal center frequency shall be proportional to the instantaneous modulating signal voltage. All FM shall be symmetrical about the nominal center frequency and shall be specified by the peak frequency deviation. This PCM controlled carrier frequency modulation technique shall be referred to as "Continuous Phase PCM/FM."

The characteristics of the S-band direct readout link interface are tabulated in Table H-4, and corresponding link margin calculations are provided in Table H-5. Characteristics of the shaped-beam antenna are summarized in H6.

H5. X-BAND DIRECT READOUT LINK

The X-band direct readout link to the FGS from the Landsat FS will be used to transmit real-time MSS data and/or real-time TM data from the Landsat FS. The FS equipment configuration for this communication link is shown in Figure H-4.

The Thematic Mapper will generate data in the NRZ-L format and will also provide a clock signal for converting the data into the NRZ-M format. When selected, this data will be used to PSK-modulate the I-channel of the X-band transmitter. The MSS will generate data in the NRZ-L format and will also provide a clock

Table H-1
Landsat FS to FGS S-band Transponder Downlink Interface Characteristics

INFORMATION		FORMAT	SUBCARRIER		CARRIER		MIN.LSF-FS EIRP dBW(1)	MIN. GSTDN G/T dB/K)		POLAR
CHANNEL	RATE		MODULATION	FREQUENCY	MODULATION	FREQUENCY		6°ELEV.	90°ELEV.	
SUBCARRIER: Realtime Telemetry (Always present)	8 kbps or 1 kbps	Biϕ-S	BPSK	1.024 MHz ±0.001%	PM β = 1.6 rad (peak sine ±10%) β = 0.8 rad (peak sine ±10%)	Mode 1 (Coherent) $\frac{240}{221}$ x Uplink freq. Mode 2 (Non-Coh.) 2287.5 MHz ±0.001%(2)	-3.3	21.0	22.0	RCP
BASEBAND: One of the following: OBC or PCD or	32 kbps 32 kbps	Biϕ-S	N/A	N/A	PM β = 1.0 rad ±10% (peak rectangular)	(Same as above)	-3.3	21.0	22.0	RCP
STR Playback	256 kbps	Biϕ-S	N/A	N/A		(Same as above)	-3.3	21.0	22.0	RCP
Ranging: Major Range Tone Minor Range Tones Command Turnaround				500 kHz(3) 100, 20 or 4 16 kHz	β (rms) = 0.6 2	(Same as above)	-3.3	21.0	22.0	RCP

Notes:
(1) Includes Landsat FS transmitter power, connection loss, antenna (omni) gain and polarization loss.
EIRP is based on: 100% coverage for stabilized FS (63.4° about nadir)
80% coverage of sphere for unstabilized FS

(2) Does not include the effect of downlink Doppler shift.

Table H-2
Link Calculations for the Landsat to FGS S-band Transponder Downlink

DOWN LINK TELEMETRY
- 8 kbps RT TELEMETRY AND
- 32 kbps OBC DATA OR
- 32 kbps PCD DATA OR
- 256 kbps STR PLAYBACK AND/OR
- GSTDN RANGING

OMNI TO FOREIGN GROUND STATION – RCP
MODULATION: PCM/PM AND PCM/PSK/PM AND/OR PM
FREQUENCY: 2287.5 MHz
SLANT RANGE: 2585 km AT 5 DEG. GROUND ELEVATION (LANDSAT ALT: 710 km)

PARAMETER		S-BAND TRANSPONDER DOWNLINK				REMARKS
TRANSMITTER POWER (5W–1dB)	dBW	+6.0				SPEC VALUE
LANDSAT CONNECTION LOSS	dB	-3.2				
LANDSAT POLARIZATION LOSS	dB	0.0				INCLUDED IN GAIN
LANDSAT ANTENNA GAIN	dB	-6.0				NOTE 1
LANDSAT EIRP	dBW	-3.2				
SPACE LOSS	dB	-167.9				
ABSORPTION & RAIN LOSS	dB	-0.5				4 mm/hr RAIN
GND. ANTENNA GAIN	dB	+42.0				NOTE 2
GND. ANT. POINT. LOSS	dB	-0.1				PEAK WINDS TO 60 mph
RECEIVED CARRIER POWER	dBW	-129.7				
No = KTs (125K@5°ELEV)	dBW/HZ	-207.6				NOTE 2
CHANNEL		1.024 MHZ S/C		BASEBAND		
BIT RATE kbps		8	8	32	256	
S/C MOD INDEX rad		1.6	0.8	0.8	0.8	
RECEIVED C/No	db-HZ	+77.9	+77.9	+77.9	+77.9	(C-No) dB
MODULATION LOSS, Lm	dB	-1.9	-12.0	-4.0	-4.0	NOTE 3
RECEIVED S/No	dB-HZ	+76.0	+65.9	+73.9	+73.9	(C/No + Lm) dB
BIT RATE, F_B	dB-HZ	+39.0	+39.0	+45.0	+54.1	
RECEIVED EB/No	dB	+37.0	+26.9	+28.9	+19.8	$(S/N - F_B)$ dB
REQUIRED EB/No (BER = 10^5)	dB	+12.9	+12.9	+12.9	+12.9	NOTE 4
MARGIN	dB	+24.1	+14.0	+16.0	+6.9	NOTE 5

NOTES: 1) FULL SCALE LANDSAT-D ANTENNA MODEL MEASURED DATA
NMSU PSL FINAL REPORT PF 00955 DECEMBER 1979, SUMMARY DATA IN H6

2) SPECIFIED VALUE FOR LINK TO GSTDN STATIONS

3)

MODULATION	1.024 MHZ SUBCARRIER	BASEBAND
WAVEFORM	PSK SINUSOID	SQUARED PCM
NOM. CAR. MOD. INDEX	0.8	1.0
NOM. MOD. LOSS	-11.0 dB	-3.0 dB (WITH S/C MOD INDEX = 0.8)
SET-UP TOLERANCE	-1.0 dB	-1.0 dB
WORST MOD LOSS	-12.0 dB	-4.0 dB

WITH S/C MOD INDEX = 1.6, WORST MOD LOSS = 1.9 dB FOR S/C, -9.5 FOR BASEBAND

4) E_B/No (Biφ-M BER = 10^{-5}) +9.9 dB
+3.0 dB (NOTE 1)

REQUIRED EB/No +12.9 dB

5) AT 90 DEGREE SLANT RANGE, ADD MARGIN TO 5 DEG. MARGIN:

Δ SPACE LOSS	+11.3 dB
Δ LANDSAT ANTENNA GAIN	+6.0 dB
Δ ABSORB./RAIN LOSS	+.2 dB
Δ MARGIN	+17.5 dB

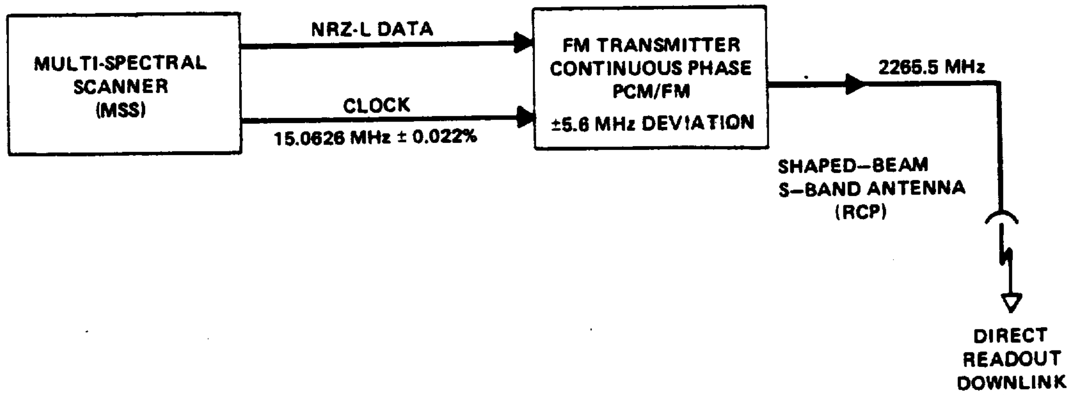


Figure H-3. Landsat FS to FGS S-band Direct Readout Downlink Configuration

Table H-3
Salient Characteristics of S-band Transmitter

Characteristics	Value
Operating frequency	2265.5 MHz
Frequency accuracy and stability	±0.0005%
Output power	15W, max; 10W, min
Modulation:	
Type	PCM-FM
Data rate	15.0626 Mbps
Format	NRZ-L, Reclocked
FM frequency deviation	±5.6 MHz (High Freq. = logic "1" Low Freq. = logic "0")
Rise time	35 ± 5 nsec

Table H-4
Landsat FS to FGS S-band, Direct Readout, Downlink Interface Characteristics

INFORMATION			CARRIER		MIN. LSD-FS EIRP (1)		ANTENNA POLARIZ.
CHANNEL	BIT RATE	FORMAT	PEAK DEVIATION	FREQUENCY	5° ELEV. dBW	90° ELEV. dBW	
MSS Sensor	15.0626 Mbps ±0.02%	NRZ-L	5.6 MHz + 5%	2265.5 MHz ±0.005%(2)	+11.0	+0.5	RCP

Notes:
(1) Includes Landsat FS transmitter power, connection loss, antenna (shaped S-band) gain and polarization loss referenced to RCP receiving antenna.
(2) Does not include effects from downlink Doppler shift.

Table H-5
Link Calculations for the Landsat to FGS S-band
Direct Readout Downlink

DOWNLINK
DIRECT READOUT S-BAND (15.06 MBPS) - RCP
TO FOREIGN GROUND STATIONS
MODULATION: PCM-FM, ±5.6 MHz DEVIATION
FREQUENCY: 2265.5 MHz
SLANT RANGES: 710 KM AT 90 DEG ELEV; 2585 KM AT 5 DEG ELEV.

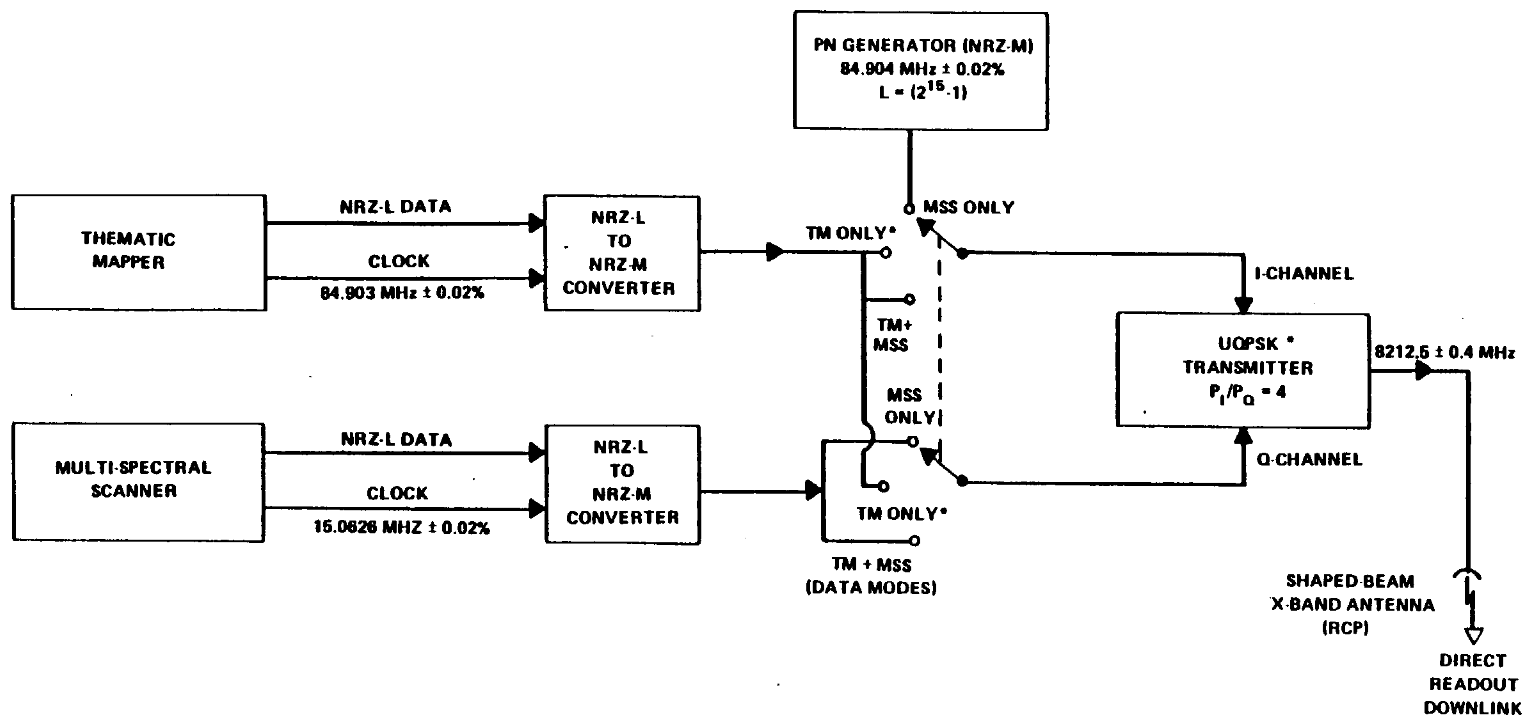
PARAMETER		5° ELEV	90° ELEV	REMARKS
TRANSMITTER POWER (10 W)	dBW	+ 10.0	+ 10.0	SPEC REQUIREMENT
LANDSAT CONNECTION LOSS	dB	- 1.5	- 1.5	CABLE, SWITCH & VSWR
LANDSAT ANTENNA GAIN	dB	+ 2.5	- 8.0	NOTE 1
LANDSAT POLARIZATION LOSS	dB	0.0	0.0	INCLUDED IN GAIN
LANDSAT EIRP	dBW	+ 11.0	+ 0.5	
SPACE LOSS	dB	-167.9	-156.6	
ABSORPTION & RAIN LOSS	dB	- 0.5	- 0.3	4mm/hr RAIN
GND. ANT. GAIN	dB	+ 42.0	+ 42.0	NOTE 2
GND. ANT. POINTING LOSS	dB	- 0.1	- 0.1	PEAK WINDS TO 60 MPH
RECEIVED CARRIER POWER, C	dBW	-115.5	-114.5	
No = K T_S (125 K @ 5° ELEV; 100 k @ 90°)	dBW/Hz	-207.6	-208.6	NOTE 2
RECEIVED C/No	dB-Hz	+ 92.1	+ 94.1	(C-No) dB
BIT RATE (15.06 MHz)	dB-Hz	+ 71.8	+ 71.8	
RECEIVED E_B/No	dB	+ 20.3	+ 22.3	(E_B/No = C/No - F_B) dB
REQUIRED E_B/No (BER - 10^{-5})	dB	+ 16.0	+ 16.0	NOTE 3
MARGIN	dB	+ 4.3	+ 6.3	NOTE 4

NOTES:
1) FULL SCALE LANDSAT ANTENNA MODEL MEASURED DATA
   NMSU PSL FINAL REPORT PF 00955 DECEMBER 1979
   SUMMARY DATA INCLUDED IN H6

2) SPECIFIED VALUE FOR LINK TO NASA TGS

3) B_{IF} = 30 MHz (ENB) NOTE 4
   T_{BIT} = 1 ÷ 15 MHz
   B_T = 2
   E_B/No (BER = 10^{-5}) = +13.5 dB
   DEMOD/DECISION LOSS + 2.5 dB
   REQUIRED E_B/No +16.0 dB

4) 1.5 dB IMPROVEMENT CAN BE ACHIEVED WITH 15 MHz B_{IF}



*WHEN TM IS SELECTED FOR BOTH I- AND Q-CHANNELS, THE MODULATION THEN BECOMES BPSK.

Figure H-4. Landsat FS to FGS X-band Direct Readout Link Configuration signal for converting the data into the NRZ-M format. When selected, this data will be used to PSK-modulate the Q-channel of the X-band transmitter. When only TM data are to be transmitted, both the I- and Q-channels will be modulated with TM data, and when only MSS data are to be transmitted, a PN code generator will be used to modulate the I-channel of the transmitter. The shaped beam X-band antenna on the Landsat FS will be used for this link. At receiving ground stations, the data clock frequencies will be subject to a slight shift ($\leq \pm 0.002$ percent) from that transmitted because of Doppler shift effects.

The X-band transmitter for the Landsat FS shall have a carrier frequency of 8212.5 $\pm$0.4 MHz. Each channel of the RF carrier shall be phase shifted between $\pm$Pi/2 radians as the modulating bilevel signal (e.g., NRZ-M) shifts between one level and the other. When both TM and MSS data are being transmitted, the TM data shall phase modulate the in-phase carrier (I-channel) of the transmitter by $\pm$Pi/2 radians and the MSS data shall asynchronously modulate the quadrature phase (Q-channel) by $\pm$Pi/2 radians. For this link, the ratio of the power in the I-channel to that in the Q-channel shall be 4:1. The modulated I-channel and Q-channel carriers shall be linearly combined and the resulting carrier phase states shall be as shown in Figure H-5.

When only MSS image data are being transmitted, TM data shall be replaced by a PN sequence with a length $L = 2^{15}-1$ at a rate of 84.903 Mbps $\pm$0.02 percent. This PN code shall phase-modulate the in-phase carrier as described above. When only TM image data are being transmitted, the data are modulated onto both the I- and Q-channels of the UQPSK transmitter, and the modulation then effectively becomes binary PSK (BPSK). In this mode of modulation, the carrier shall be phase shifted $\pm$Pi/2 radians as the modulating signal shifts between its two levels, and the I-channel carrier phase shall lead the Q-channel phase by Pi/2 radians.

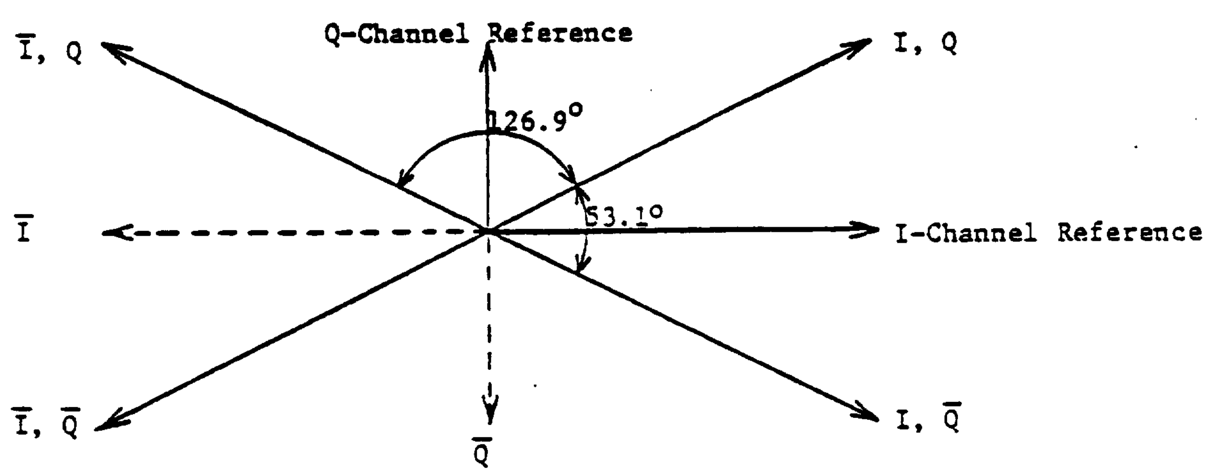


Figure H-5. UQPSK Phase Diagram

The characteristics of the X-band direct readout link interface are tabulated in Table H-6, and corresponding link margin calculations are provided in Table H-7. Characteristics of the shaped-beam X-band antenna are summarized in H6.

H6. SUMMARY DATA ON Landsat-4 FS ANTENNA CHARACTERISTICS

To obtain RF performance characteristics of the S-band and X-band antennas planned for use on the Landsat-4/-5 FS, the General Electric Company contracted the Physical Sciences Laboratory of New Mexico State University (NMSU/PSL) to conduct full-scale power contour tests of these antennas. A full-scale test model of the Landsat-4 FS was constructed by the NMSU/PSL from drawings supplied by GE. This model duplicated the features of the FS that were critical to the RF characteristics of the S-band and X-band antenna systems on the FS. The modeling was based upon the experience of the laboratory in conducting similar tests for GE on antennas for Nimbus and previous Landsat spacecraft. The testing was conducted with the FS model mounted atop a 70-foot tower at the antenna range of NMSU/PSL at Las Cruces, New Mexico. The S-band and X-band antennas for the tests were supplied by GE and a simulated, operating model of the S-band portion of the high gain antenna was fabricated by NMSU/PSL.

The results of these tests were documented in NMSU/PSL Report No. PF0095 entitled "Full Scale Landsat-4 Antenna Pattern Measurements." Selected characteristic plots pertinent to the discussions in this appendix have been selected from that report and are included herein:

Link	Gain Pattern	Power Contour
S-band Transponder	Figure H-6	Figure H-7
S-band Direct Readout	Figure H-8	Figure H-9
X-band Direct Readout	Figure H-10	Figure H-11

Table H-6

Signal Parameters for the X-band Direct Readout Downlink from the Landsat FS to FGS

INFORMATION				LANDSAT FS TRANSMISSION				
CHANNEL	DATA	FORMAT	RATE (2)	CARRIER MODULATION	CARRIER FREQUENCY	Nominal EIRP dBW (3)		Ant. Polar.
						5° Elev.	90° Elev.	
TM SENSOR ONLY								
I-Channel Q-Channel	TM TM } (1)	NRZ-M	84.903 Mbps ±0.02%	UQPSK Power Ratio $\frac{P_I}{P_Q} = 4$ (Nominal) $P_I = 80\% \pm 5\%$ $P_Q = 20\% \pm 5\%$	8212.5 MHz ±0.4 MHz	22.8	6.8	RCP LSD FS: AR ≤ 4.0 dB GND. STA: AR ≤ 3.0 dB
MSS SENSOR ONLY								
I-Channel	PN	NRZ-M	84.903 Mbps ±0.02%	(Same as Above)	(Same as Above)	(Same as Above)		(Same as Above)
Q-Channel	MSS	NRZ-M	15.0626 Mbps ±0.02%					
TM & MSS SENSORS								
I-Channel Q-Channel	TM MSS	NRZ-M NRZ-M	(Same as Above)	(Same as Above)	(Same as Above)	(Same as Above)		(Same as Above)

NOTES:

(1) Modulation of both I&Q channels by the same data is equivalent to BPSK modulation

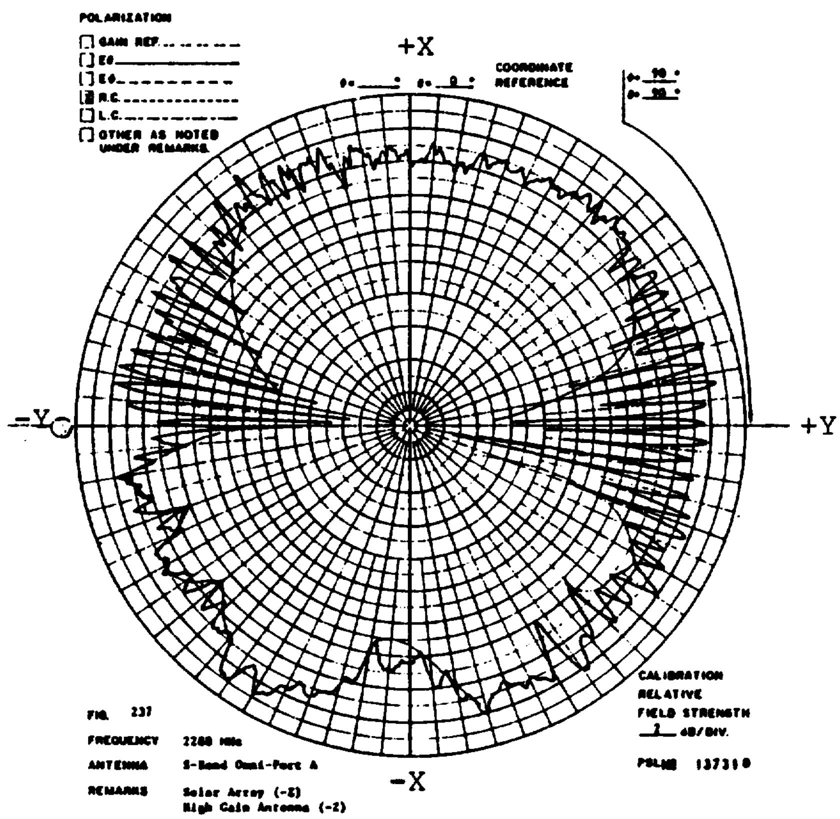
(2) Does not include effects from downlink Doppler shift

(3) Includes Landsat FS transmitter power, connection loss, antenna (shaped) gain, pointing loss, and polarization loss.

Table H-7
Link Calculations for the Landsat to FGS X-band Direct Readout Downlink

DOWNLINK
DIRECT READOUT, X-BAND
TM (84.903 Mbps) AND MSS (15.06 Mbps) SENSOR DATA – RCP
SHAPED BEAM TO FOREIGN GROUND STATIONS
FREQUENCY: 8212.5 MHz
SLANT RANGES: 710 km AT 90° ELEV; 2385 km AT 5° ELEV

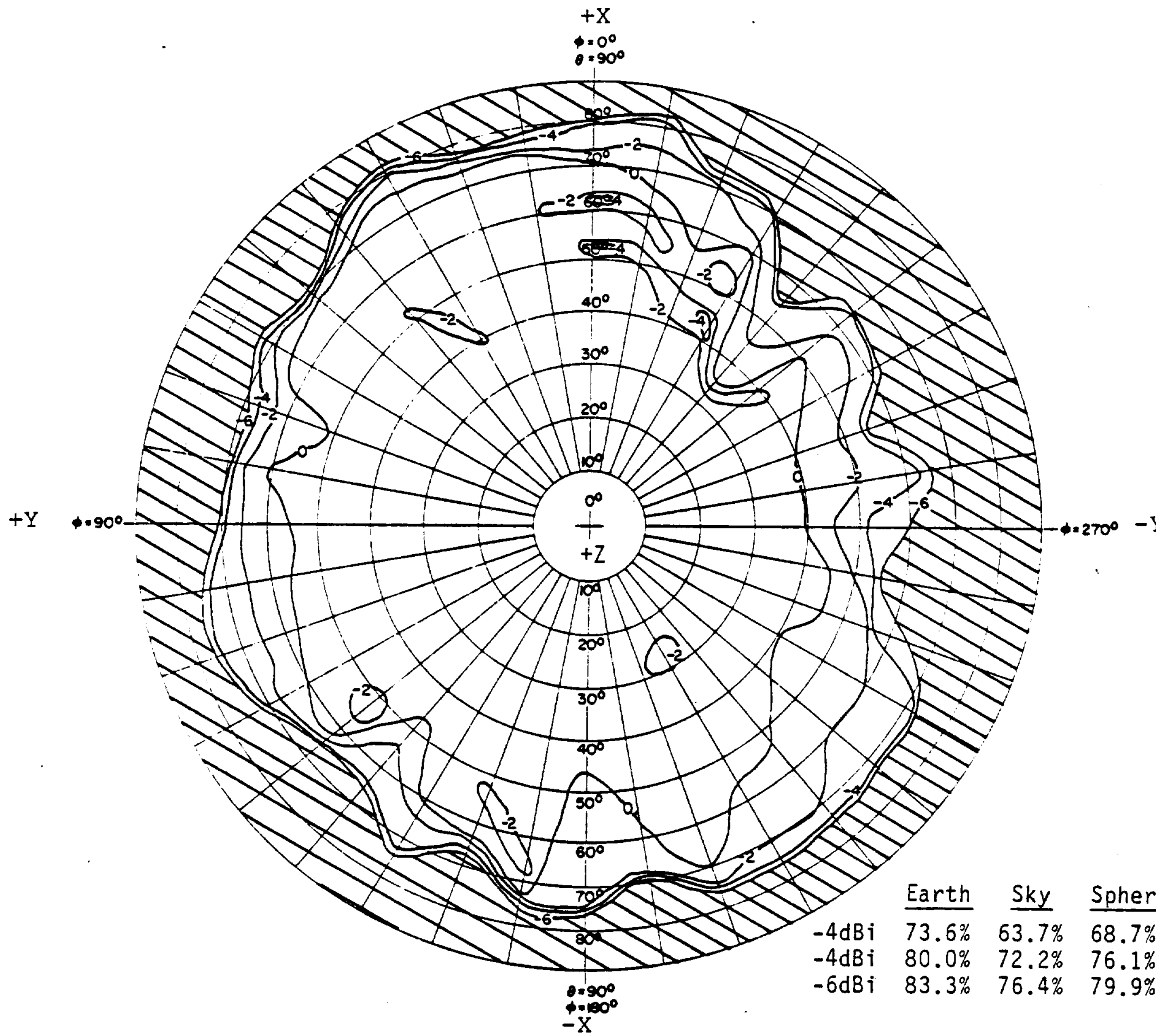
PARAMETER	NOMINAL VALUE 5° ELEV.	NOMINAL VALUE NADIR	ADVERSE TOLERANCE	NOTES
SPACECRAFT TRANSMITTER POWER (dBW)	16.7	16.7	-0.3	46.7 W (BOL)
SPACECRAFT TRANSMIT LINE LOSS (dB)	-0.6	-0.6	-0.3	FROM LINE LOSS BUDGET
SPACECRAFT ANTENNA GAIN (dBi)	+7.0	-9.0	-1.0	REF. FULL SCALE F/S ANT. MODEL NMSU/PSL PF00955 & H6
SPACECRAFT EIRP (dBW)	23.1	7.1		
SPACE LOSS (dB)	-178.9	-167.7		705.3 km ALTITUDE AT ZENITH; 8.2 GHz
ABSORPTION (dB)	-0.9	-0.1		CLEAR WEATHER
RAIN ATTENUATION (dB)	-2.0	-0.2		4 MM/HR
POLARIZATION LOSS (dB)	-0.3	-0.3	-0.2	SPACECRAFT AXIAL RATIO = 4.0 dB GROUND AXIAL RATIO = 2.0 dB
GROUND STATION ANTENNA GAIN (dB)	54.0	54.0		9 M DISH (INCL. POINTING LOSS)
TOTAL RECEIVED SIGNAL POWER (dBW)	-105.0	-107.2		
SYSTEM NOISE TEMPERATURE (°K)	200.0	171.3		
SYSTEM NOISE SPECTRAL DENSITY (dBW/Hz)	205.6	206.3		
INCREASED SKY TEMP. DUE TO RAIN (dB)	-10.9	-0.2		ΔT SKY = 10.5°K; 4 MM/HR RAIN
RECEIVED SIGNAL TO NOISE DENSITY RATIO (dB/Hz)	+98.7	+98.9		
84.903 MBPS TM DATA PERFORMANCE (I-CHANNEL)				
POWER SPLIT LOSS (dB)	-1.0	-1.0	-0.2	
DATA RATE (dB/Hz)	-79.3	-79.3		84.903 MHz
GAIN FLATNESS LOSS (dB)	-0.3	-0.1		3.0 dB p.p., 116 MHz PERIOD DUE TO MULTIPATH OFF SOLAR ARRAY
PHASE NONLINEARITY LOSS (dB)	-1.5	-0.5		20 DEG p.p., 116 MHz PERIOD DUE TO MULTIPATH OFF SOLAR ARRAY
RECEIVED E_B/N_0 (dB)	16.6	18.0		
REQUIRED E_B/E_0 (dB)	13.3	13.3		ΔPSK AT 10^{-6} BER INCLUDES 2.6 dB RECEIVER DEGRADATION
NOMINAL SYSTEM MARGIN (dB)	3.3	4.7	-1.1 (RSS)	
WORST CASE MARGIN (dB) (RSS)	2.2	3.6		ADD 1.0 dB TO MARGIN FOR TM TRANSMISSION ONLY; TM MODULATES BOTH I- AND Q-CHANNELS AND THE RECEIVER IS CONFIGURED FOR BPSK RECEPTION
15 MBPS MSS DATA PERFORMANCE (Q-CHANNEL)				
POWER SPLIT LOSS (dB)	-7.0	-7.0	-0.2	20% OF TWTA POWER FOR MSS DATA
DATA RATE (dB/Hz)	-71.8	-71.8		15.06 MBPS
RECEIVED E_B/E_0 (dB)	19.9	20.1		
REQUIRED E_B/E_0 (dB)	12.4	12.4		ΔPSK AT 10^{-5} BER INCLUDES 2.5 dB RECEIVER DEGRADATION
NOMINAL SYSTEM MARGIN (dB)	7.5	7.7	-1.1 (RSS)	
WORST CASE MARGIN (dB) (RSS)	6.4	6.6		



Reference: Figure 237 of NMSU/PSL PF 00955

Applicable to: S-band Transponder Downlink

Figure H-6. Gain Pattern of S-band Omni Antenna



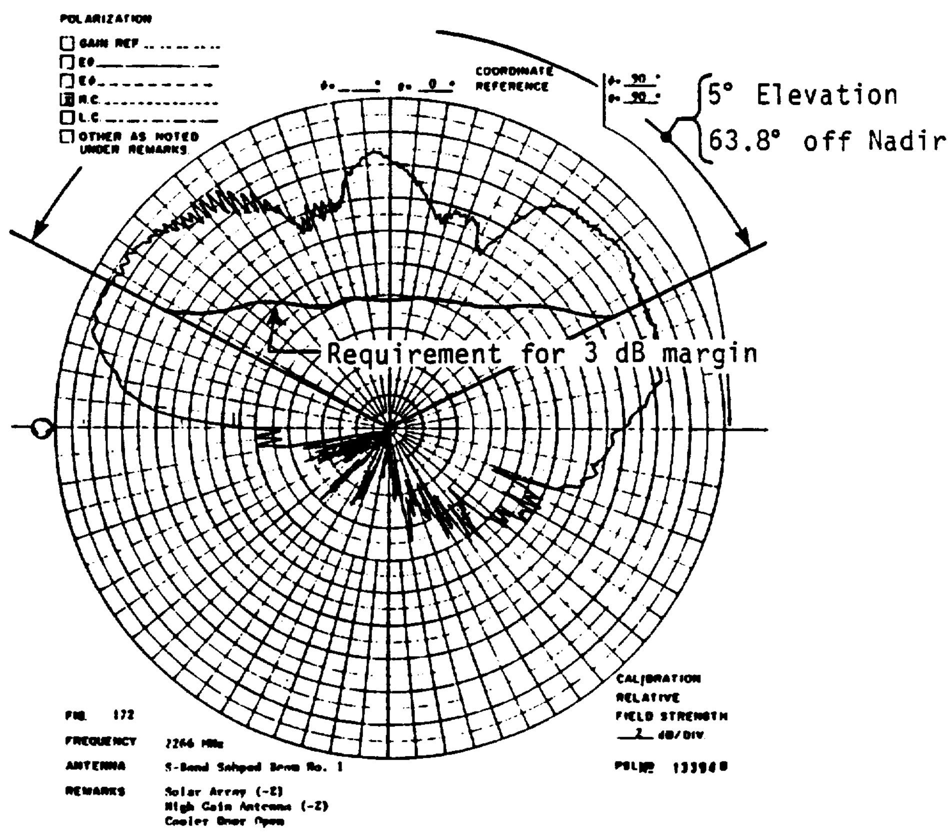
	Earth	Sky	Sphere
-4dBi	73.6%	63.7%	68.7%
-4dBi	80.0%	72.2%	76.1%
-6dBi	83.3%	76.4%	79.9%

POWER CONTOUR GRAPH			
PROGRAM	LANDSAT-D	POLARIZATION	R.C.
ANTENNA	S-Band Omni Array - Port A	GAIN REFERENCE	SGH-1.7 HORN
FREQUENCY	2287.5 MHz	ENGINEER	C.C. Post
MODEL SCALE	FULL		
REMARKS *Coverage calculated on basis of 50% cov. in equatorial areas.			
	SOLAR ARRAY (-Z)		
	HIGH-GAIN ANTENNA (-Z)		
	COOLER DOOR OPEN		

Reference: Figure 232 of NMSU/PSL Report PF00955

Applicable to: S-band Transponder Downlink

Figure H-7. Power Contour Graph of S-band Omni Antenna



Reference: Figure 172 of NMSU/PSL Report PF 00955

Applicable to: S-band Direct Readout Link

Figure H-8. Gain Pattern of S-band Shaped Beam Antenna

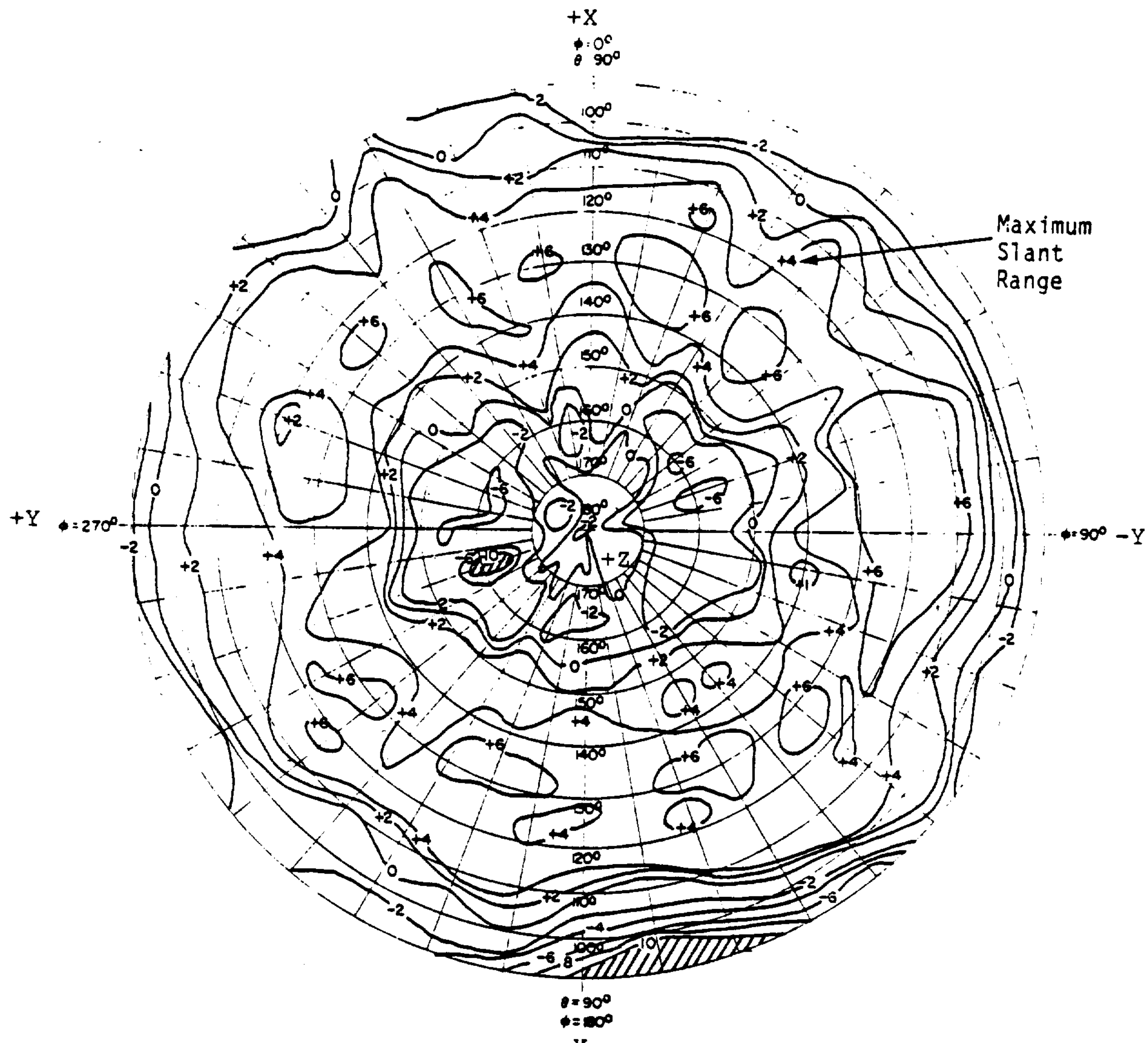
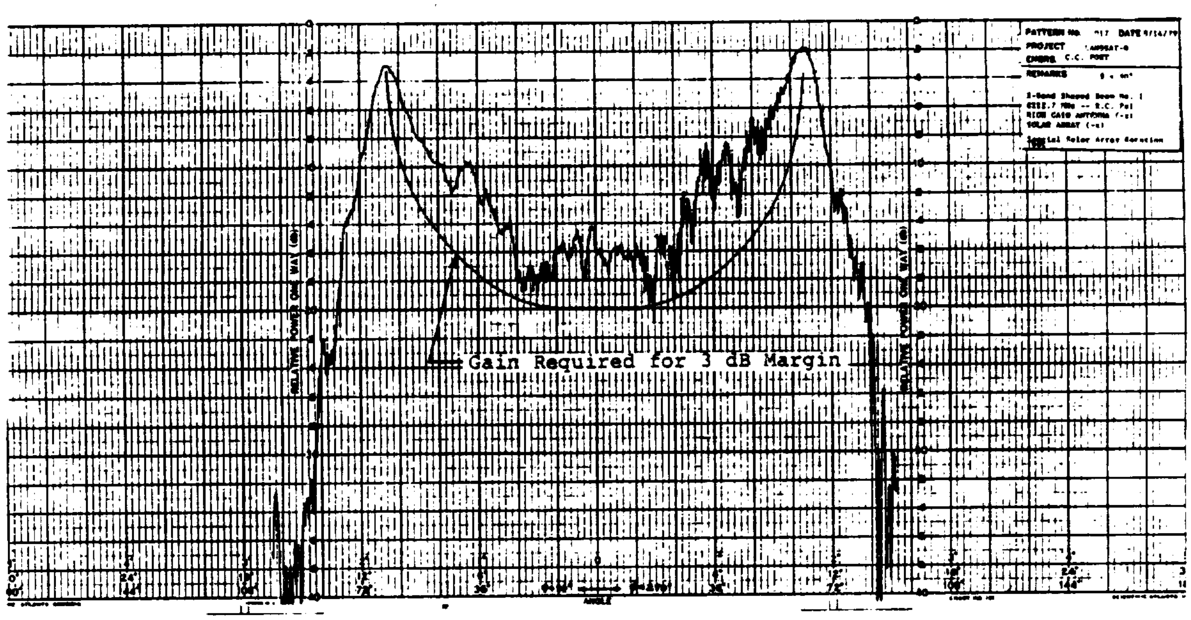


FIG. NO. 160 POWER CONTOUR GRAPH			
PROGRAM	LANDSAT-D	POLARIZATION	R.C.
ANTENNA	S-Band Shaped Beam #1	GAIN REFERENCE	SGH-1.7
FREQUENCY	2266 MHz	ENGINEER	C.C. Post
MODEL SCALE	FULL		
REMARKS			
	SOLAR PANEL (-X)		
	HIGH-GAIN ANTENNA (-Z)		
	THEMATIC MAPPER COOLER DOOR CLOSED - (COMPARE FIGURE 151)		

Reference: Figure 160 of NMSU/PSL Report PF00955

Applicable to: Link 9 - S-Band Direct Readout Link

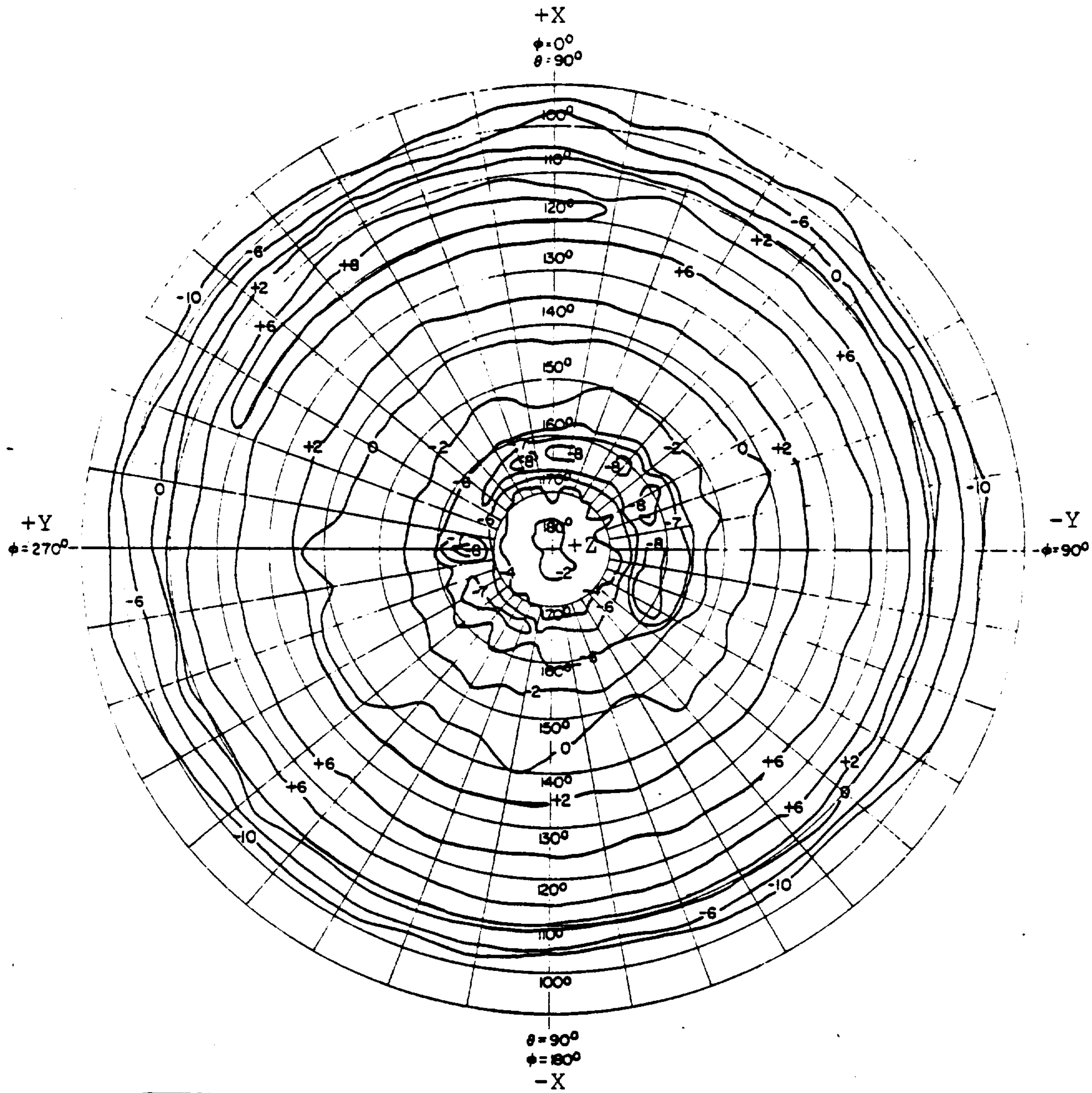
Figure H-9. Power Contour Graph of S-band Shaped Beam Antenna



Reference: Figure 364 of NMSU/PSL Report PF00955

Applicable to: X-band Direct Readout Link

Figure H-10. Gain Pattern of X-band Shaped Beam Antenna



POWER CONTOUR GRAPH			
PROGRAM	LANDSAT-D	POLARIZATION	R.C.
ANTENNA	X-Band Shaped Beam	GAIN REFERENCE	SGH-5.8 HORN
FREQUENCY	8212.5 MHz	ENGINEER	C.C. Post
MODEL SCALE	FULL		
REMARKS			
	SOLAR PANEL REMOVED		
	HIGH-GAIN ANTENNA REMOVED		
	COOLER DOOR OPEN		

Reference: Figure 369 of NMSU/PSL Report PF 00955

Applicable to: X-Band Direct Readout Link

Figure H-11. Power Contour Graph of X-band Shaped Beam Antenna